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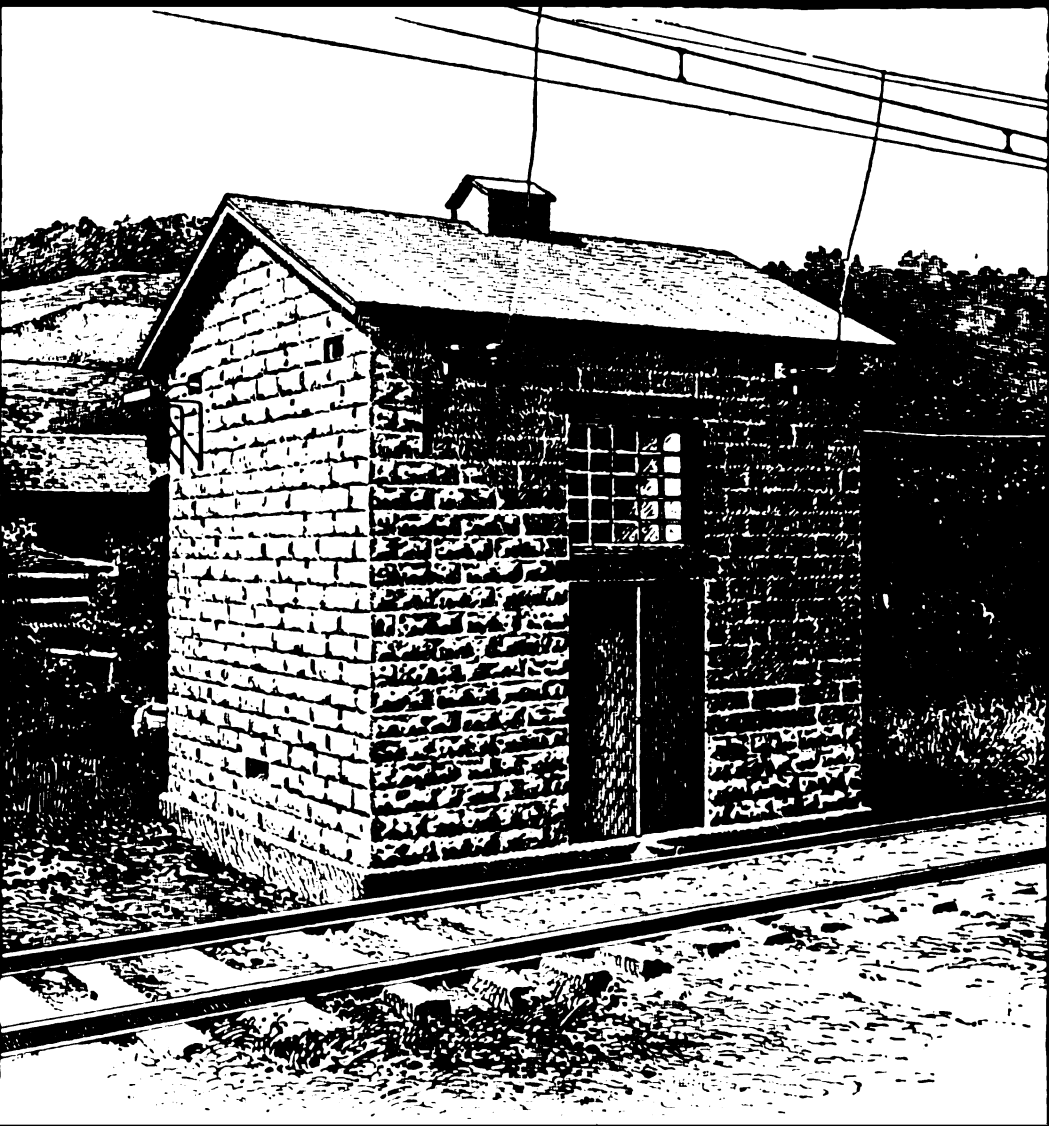

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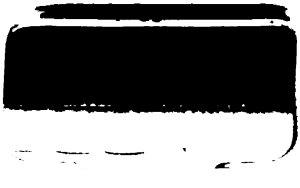

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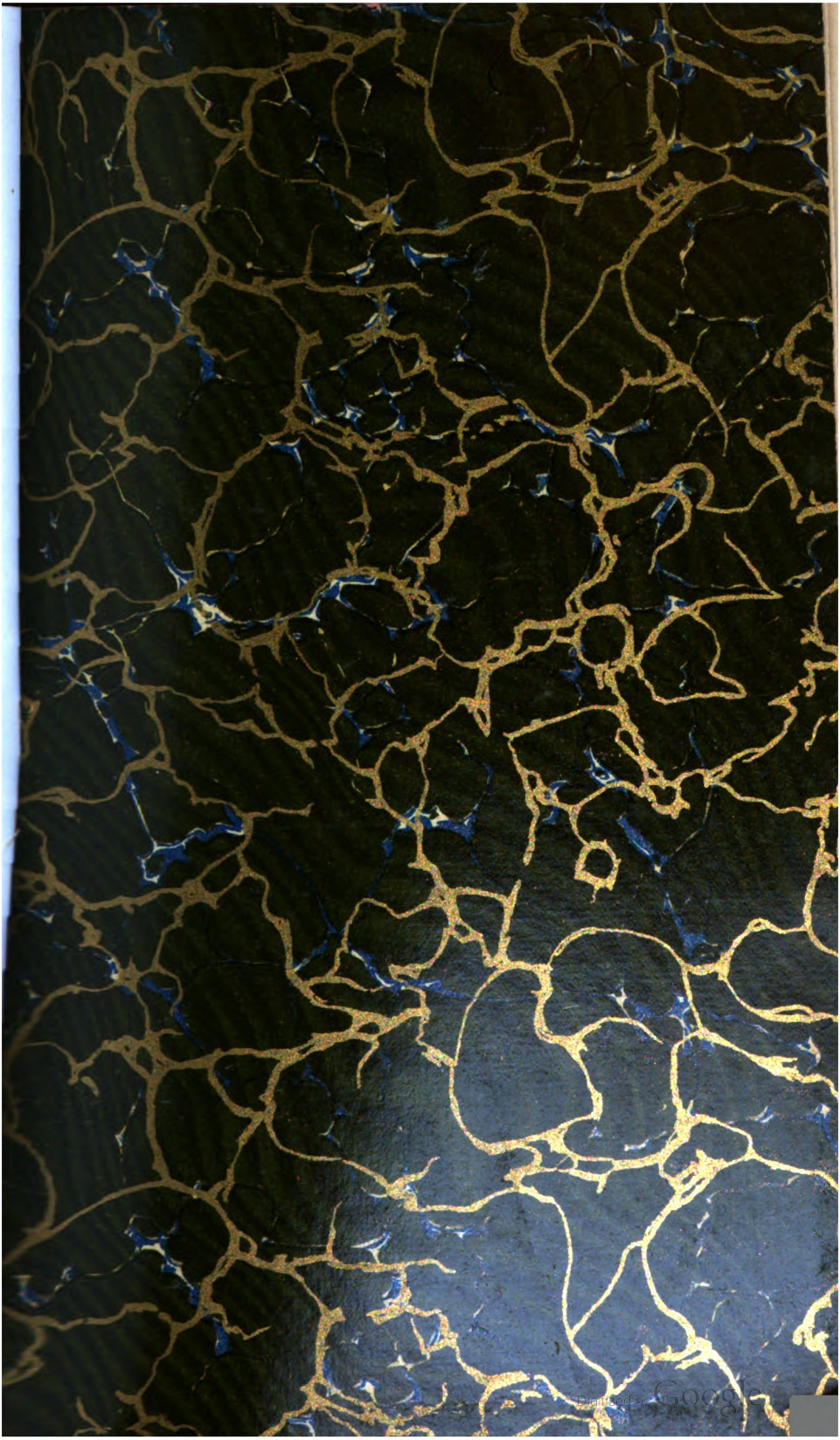
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TRANSMISSION SYSTEMS FOR HEAVY TRACTION
TYPES OF COLLECTORS FOR HEAVY TRACTION
TYPES OF RAILWAY MOTORS
SPEED CONTROL
SINGLE-PHASE SPEED CONTROL
ELECTRIC LOCOMOTIVES
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PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools, is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one, or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

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In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice—together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the

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indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one to select the proper formula, method, or process and in teaching him how and when it should be used.

The contents of this volume relate to systems for the transmission of electrical energy for the propulsion of electric locomotives and electric trains; to the apparatus used on the locomotives and trains for collecting the current, for propulsion, for acceleration of the speed, and for braking; to instructions for the operation of the locomotives and trains; and to signal systems used in connection with heavy electric traction. The general features of the transmission systems are explained. Third-rail and catenary construction are treated in considerable detail. Types of collectors suitable for the collection of large currents and for high-speed service are described and illustrated. Instructions are provided relating to the commutating-pole motor and to other types of direct-current and alternating-current railway motors. The important subject of speed control receives a most comprehensive treatment. Numerous multiple-unit wiring diagrams, some in four colors, aid in the study of this complex problem. Three sections are devoted to the subject of brakes. The operating features of the signal systems used on electric railroads are explained.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 16, page 26, will be readily found by looking along the inside edges of the headlines until § 16 is found, and then through § 16 until page 26 is found.

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TRANSMISSION SYSTEMS FOR HEAVY TRACTION

POWER STATIONS

MAIN GENERATING STATIONS

SMALL DIRECT-CURRENT STATION

1. The generators, engines, boilers, and pumps, together with the switchboards and other devices necessary to the safe and economical generation and distribution of power for an electric road, are located under one roof, the whole constituting what is variously known as the **power plant, power station, station,** or **power house.**

In Fig. 1 is shown one of the simplest types of station, from which direct-current power is transmitted directly to the cars. An engine S drives a compound-wound generator D, which sends current through the devices on a switchboard K and the feeder cable to the trolley wire, thence through the car motors to the track rails and back through the rails to the generator, as indicated by the arrowheads.

The bus-bars are large copper conductors, and are usually mounted behind the switchboard. The feeders are connected to the positive bus-bar, and the ground cable is connected to the negative bus-bar. The circuit-breakers are automatic switches that open in case an excessive current passes through them. In low-tension work, the break is made in the air, while in high-tension work it is made in a vessel that is nearly filled with insulating oil.

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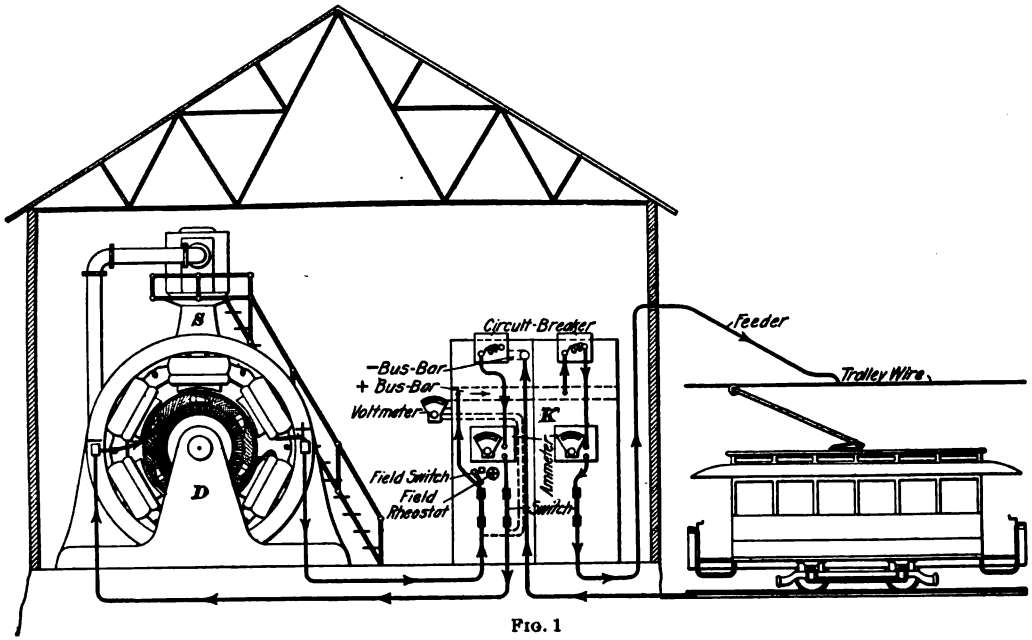

FIG. 1

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ALTERNATING-CURRENT STATIONS

2. In large electric-railroad systems, there are usually one or more power stations centrally located regarding load conditions, and in these stations alternating current is generated. The alternating current at high tension is transmitted to substations, where, by means of transformers and rotary converters, it is transformed into direct current of the proper voltage for use in propelling the cars.

In some systems where alternating-current motors are used to propel the cars, the rotary converters are dispensed

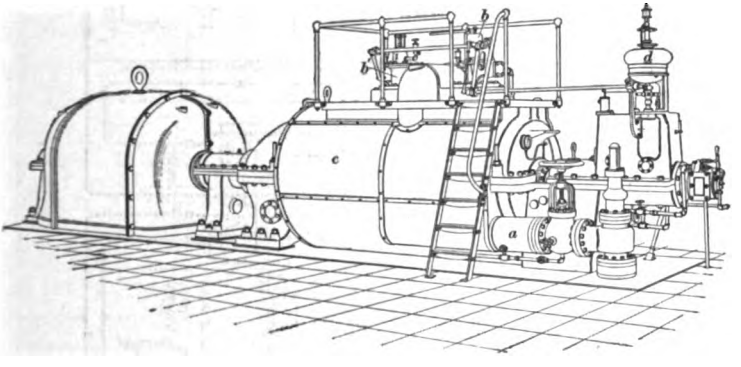

FIG. 2

with, and if the transmission voltage is high and the road not too long, the substations may also be omitted. In such cases, an autotransformer on the car steps down the electromotive force between the trolley and the ground to a value suitable for the alternating-current car motors.

3. Steam Turbines.—In many modern stations, **steam turbines** connected directly to alternating-current generators are used. In the steam turbine, the steam is forced against small blades, or buckets, mounted on a revolving shaft, by the directive agency of nozzles or stationary blades mounted on the turbine frame. The revolving field of the generator is mounted on a continuation of the turbine shaft and is driven at a high speed.

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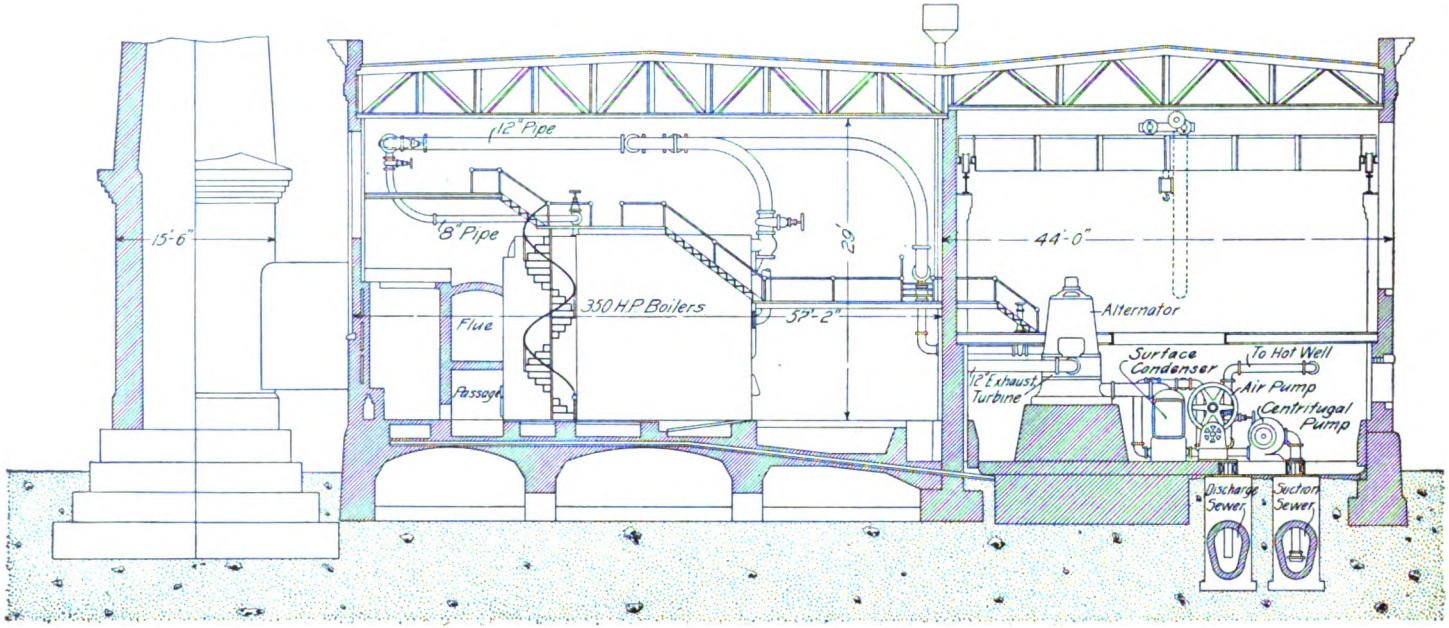

FIG. 8

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For a given output, the turbine-generator set, either of the vertical or the horizontal type, occupies much less space than the set consisting of a reciprocating engine and a low-speed generator.

In Fig. 2 is shown a *Westinghouse-Parsons turbo-alternator* of the horizontal type. The steam enters at *a* and passes through one or both of the governing valves *b*, *b'* on the turbine, and thence between the sets of stationary and revolving blades contained in casing *c* to a device called a *condenser*. In the condenser the steam is turned to water and a vacuum is formed at the exhaust end of the turbine, thus increasing the efficiency of the machine.

The fly-ball governor is located at *d* and is connected to pilot valves controlling steam valves *b*, *b'*. The alternating-current generator connected to the steam turbine is shown at the left of the illustration and is entirely enclosed, but by means of small fan blades located on the shaft and air passages in and under the generator, it is made self-ventilating.

4. Arrangement of Station Apparatus.—In Fig. 3 is shown the general arrangement of the boilers, Curtis steam turbines of the vertical type, alternating-current generators, and various auxiliary apparatus used in a central power station. The switchboard on which the control apparatus and the measuring instruments are mounted is usually placed on a gallery overlooking the generator room.

The active portions of the high-tension switches are enclosed in vessels containing insulating oil. When the circuit is opened, the break takes place in the oil and little if any sparking occurs. The switches are operated through the action of magnets connected by low-tension circuits to the switchboard. The measuring instruments are also connected through transformers to the high-tension circuits. By this means, only low-tension circuits are connected to the switchboard, and danger of shock to the operator and damage to the apparatus is thus lessened.

It is beyond the scope of this Section to describe in detail the switching system of a modern power station.

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SUBSTATIONS

ROTARY-CONVERTER SUBSTATION

5. Arrangement of Substation Apparatus.—The power station and the substations of a railway system using direct current for propelling the cars are usually connected by three-phase, alternating-current circuits. The alternating current is transformed into direct current for the third rail by means of the apparatus in the substation. The arrangement of the apparatus may be varied to conform to local conditions.

In Fig. 4 is shown the interior of a substation of a long-distance electric road. The building is divided into two sections—the operating room and the high-tension department. The operating room contains the transformers, reactance coils, rotary converters, and switchboard, while the high-tension apparatus, which includes oil switches, lightning arresters, choke coils, and primary bus-bars, is located in the high-tension department.

6. Connection of Substation Apparatus.—In Fig. 5 is shown the more important connections of the alternating-current apparatus. The 60,000-volt, three-phase transmission line wires enter through large openings in the rear wall of the building, these openings being protected on the outside by a weather-proof hood. On the inside of the building, each line wire branches. One branch wire connects a disconnecting switch and a lightning arrester to the ground. Thus, if the line wire should receive a very high charge, such as that due to lightning, this arrester circuit will afford a path to the ground for the high-tension charge and in this way protect the other pieces of apparatus in the substation. The other branch wire connects disconnecting switch *a* and choke coil *b* to one of the high-tension bus-bars *c*. The purpose of the choke coil is to divert, by its reactance, the lightning discharge through the arrester circuit to ground.

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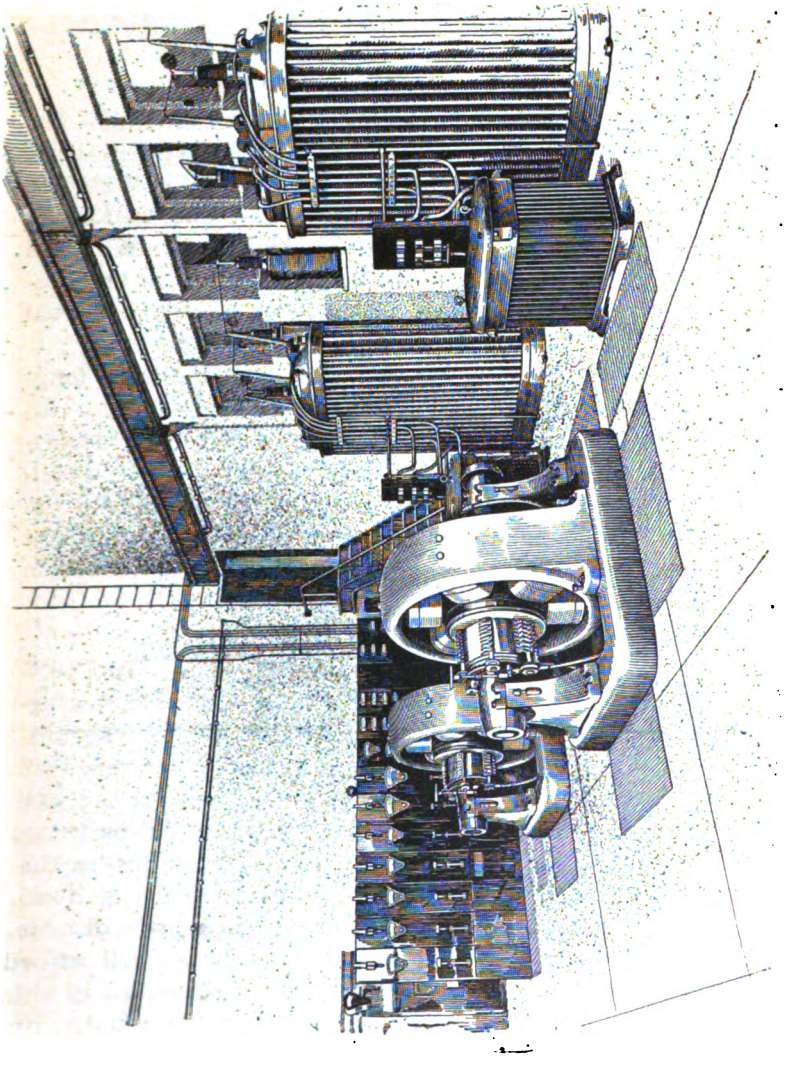

FIG. 4

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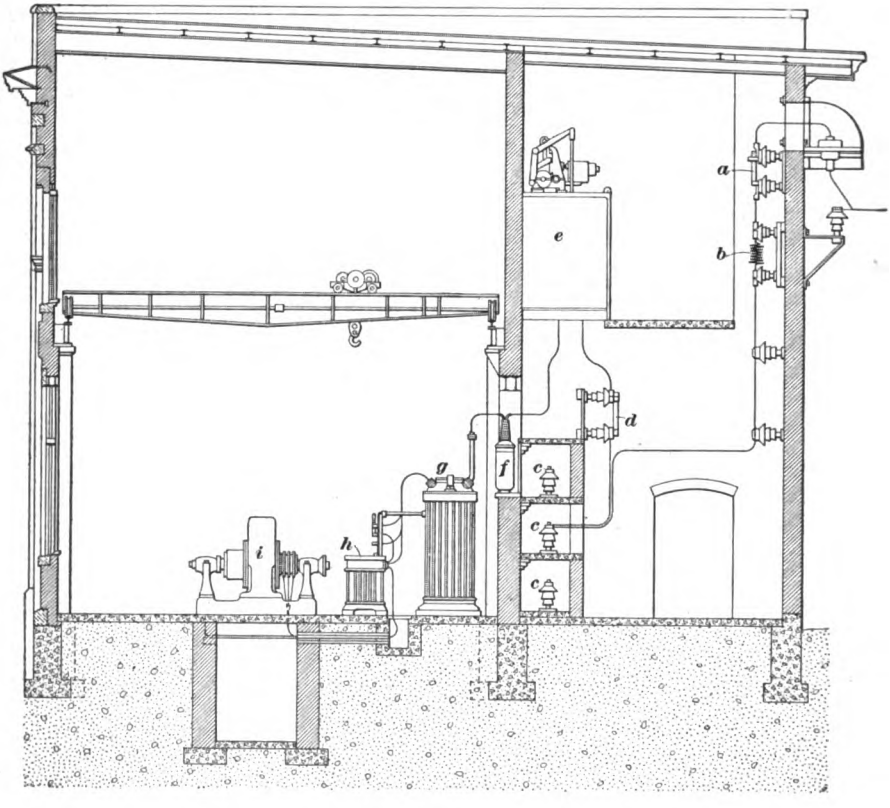

FIG. 5

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The other line wires of the three-phase circuit are arranged in a similar manner and are connected to the two remaining high-tension bus-bars.

From the bus-bars *c*, wires lead to disconnecting switches *d*, oil switches *e*, current transformers *f*, and main transformers *g*. The oil switches are provided with remote control apparatus that is operated from the switchboard. Reactive coils *h*, which are in circuit between the secondary side of the transformers and the alternating-current side of the rotary converters *i*, aid in the regulation of the direct-current electromotive force of the rotary converter. The direct-current side of the rotary converter is connected through the direct-current switchboard to the third rails.

The current transformer *f* has only a very few turns in its primary coil, which is connected in series with the line. Its secondary coil, which consists of a larger number of turns of wire carefully insulated from the primary coil, is connected to the alternating-current ammeters on the switchboard. Thus, no high-tension circuit is connected to the switchboard. The current transformers stand in recesses in the wall, as shown in Fig. 4.

7. Boosters.—In case long feeders extend from the direct-current substation to outlying sections of the railroad system, the drop in voltage in these feeders may be excessive and the electromotive force at the distant points very low. To increase the voltage at the end of the long feeders, **a booster** is sometimes employed. The booster usually consists of a series-wound dynamo that is driven by an engine or a motor and is connected in series with the long feeders. The electromotive force of the booster is added to the electromotive force of the rotary converters, so that, even with a large line drop in voltage, the electromotive force at the distant points may be normal or nearly so.

8. Storage Batteries.—In many substations, **storage batteries, secondary batteries,** or **accumulators,** as they are variously called, are installed. These batteries differ from ordinary primary batteries in the following

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particulars: In an ordinary primary cell, certain chemicals are supplied, and the chemical action set up produces an electromotive force, which in turn causes an electric current to flow at the expense of the consumption of a metal. For example, in the voltaic cell, zinc is acted on by sulphuric acid and current is produced. The zinc is eaten away during the process.

In a storage cell, the substances that, by chemical changes, produce current are not supplied to the cell from outside, but are built up in the cell by sending a current through it from some outside source. When the cell is charged by sending current through it, the current causes certain substances to be formed in the cell; when the cell is disconnected from the source of current and connected to a circuit through which it can send current, it discharges, and the substances formed by the charging process are changed back to their original condition. The cell is then recharged by sending current through it, and the process of charging and discharging can be repeated many times before the cell is worn out.

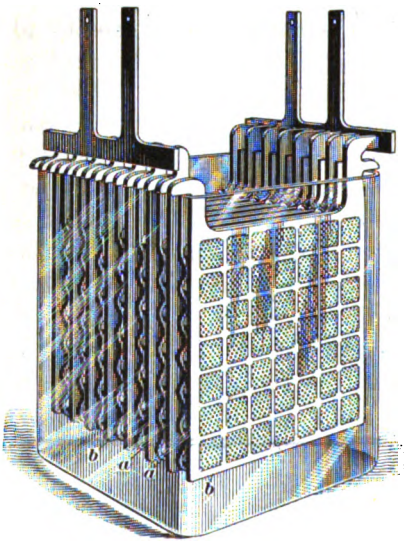

FIG. 6

Storage cells are nearly always made of specially prepared lead plates immersed in an *electrolyte*, which is a mixture of sulphuric acid and water. The plates are divided into two sets, or groups, as in Fig. 6, which shows a typical storage cell. The positive plates *a* are placed between the negative plates *b*. When a storage cell is being charged, current flows in at the positive plates and out at the negative. When it discharges, current flows out at the positive and in at the negative. The

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plates are specially prepared so as to present a large surface to the electrolyte. The plates in Fig. 6 are shown mounted in a glass jar; where cells are used for portable work, they are generally mounted in hard-rubber jars, as glass is too liable to break.

Storage cells have an electromotive force of about 2.04 volts when beginning to discharge; but as the discharge continues the electromotive force falls, so that for the last part of the discharge it may be from 1.9 to 1.8 volts.

9. Storage Batteries in Substations.—One of the important features of the storage battery is its ability to deliver heavy currents for short intervals. It is therefore very valuable as an auxiliary in power plants or substations to steady the load. In railway power stations, the load varies between wide limits, and the generators or rotary converters must meet the demands of the maximum load, which may easily be twice the average load, but which may not continue for more than 2 hours during the day. In the remaining time, a lot of machinery is idle, and idle machinery represents money that is paying no interest. By installing a storage battery in the substation, the efficiency of the substation is increased, because during the non-rush hours the rotary converters can charge the batteries and operate the road at the same time; this keeps all machinery loaded more nearly to the point of greatest efficiency. The storage battery is connected in parallel with the rotary converters. During the rush hours, the battery discharges and helps the machinery carry the load, so that not so much machinery is needed. Storage batteries are also profitably used for raising the voltage on trolley sections supplied by long or temporarily overloaded feeders. A method of increasing the voltage on a large system is to load the batteries on a car and run the car out to the points that need help most. By connecting the battery across the line at this point, it can be charged from the line during light traffic; and then during rush hours the battery can deliver current to the overloaded part of the system with comparatively little line loss.

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ALTERNATING-CURRENT SUBSTATIONS

10. Necessary Apparatus.—For railway systems employing alternating-current motors on the cars, the substations, where used, are equipped with stationary transformers and accompanying control switches. No moving

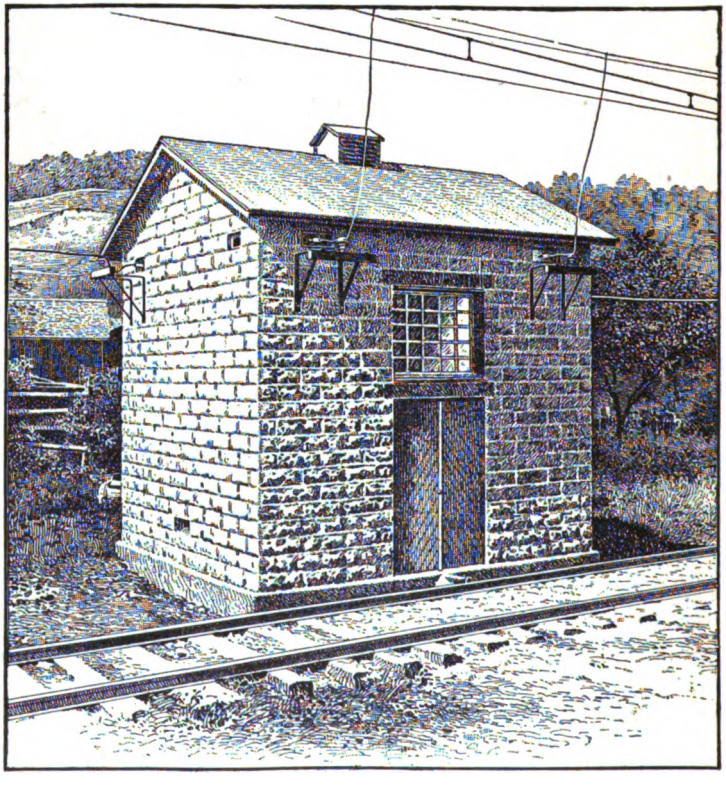

FIG. 7

machinery is employed, and, aside from inspection and the resetting of the fused circuit-breaker, the substation requires little attention. Sometimes, the substation is so located that an employe engaged on other work may, when necessary, be called by an automatic signal to attend to the circuit-breakers.

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In Fig 7 is shown the exterior, and in Fig. 8 the interior, of a substation suitable for a single-phase, alternating-current railroad system. The generators at the main station may be single-phase, two-phase, or three-phase. Usually, only one phase is employed for the railway work. The single-phase current at the main power station is stepped up to a pressure of 22,000 volts, or perhaps higher, for the transmission lines.

In the substation, step-down transformers *a*, Fig. 8, are installed. The low-tension sides of these transformers are

FIG. 8

connected between the trolley wire and the ground. The trolley pressure varies from 3,000 to 11,000 volts on different systems.

Each of the high-tension wires leading to the primary coils of the transformers is provided with high-potential, fused circuit-breakers *b*. The movable arm of the circuit-

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breaker falls down when the fuse blows and thus disrupts the arc. One end of each of the secondary coils is grounded. The other ends of these coils may be connected to either one or both of the outgoing trolley sections. Oil switches *c*, *d*, *e*, disconnecting switches *f*, and fuse block *g* assist in making connections between the secondary coils and the two trolley sections *h*. Switches *f* are provided for entirely disconnecting various parts of the system, but they are not intended to be operated when current is on the line. Coils *i* are choke coils used in connection with lightning arresters to protect the substation apparatus.

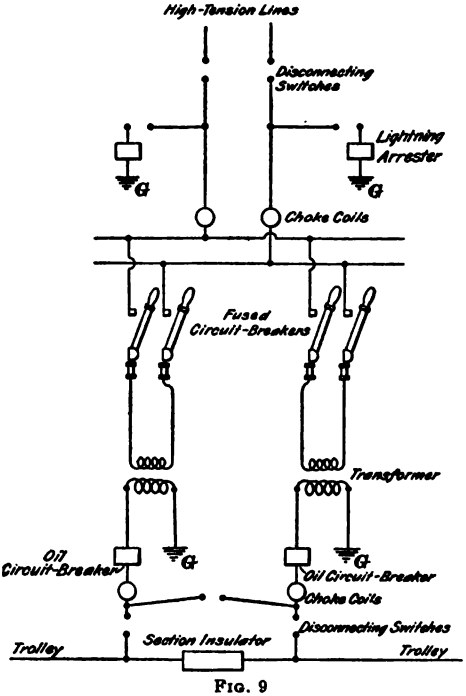

FIG. 9

11. Connections for Alternating-Current Substations.—In Fig. 9 is shown one method of connecting up the apparatus of an alternating-current substation. The arrangements vary in different stations according to local conditions. With the arrangement shown, either one or both of the transformers may be connected to either one or both of the trolley sections. On long roads built for heavy service, substations are installed at intervals in order to reduce the current flowing through the rails and thus prevent a large drop in voltage.

12. In Fig. 10 is shown another set of connections suitable for a substation of a single-phase railway system.

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Automatic safety devices, called time-limit relays, are provided to open the circuits in case of a serious short circuit of considerable duration, but for temporary short circuits, the relays do not allow the substation to be cut out. **Differential relays** are installed to open the circuit in case the trolley line, owing to some disorder, causes the secondary coil to act as a primary. As long as the power transformer is in proper condition, the secondary currents of the

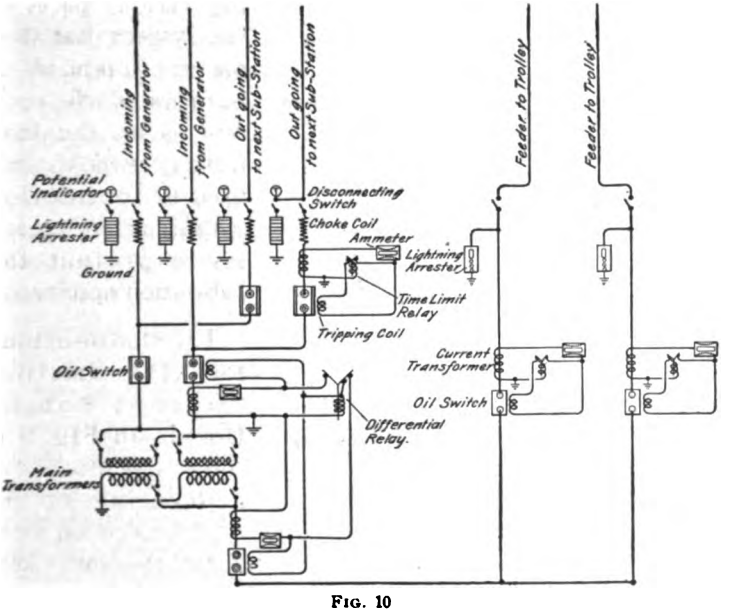

FIG. 10

two series transformers connected to the differential relay flow in the same direction at the same instant and have a closed circuit through the relay contact. If a breakdown should occur in the power transformer, the currents in the secondaries of the series transformers will buck each other and the combined current will pass through the trip coil of the relay; this action will raise the relay contact piece and force the secondary currents through the trip coils of the oil switches, thus opening these switches.

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TRANSMISSION SYSTEMS

A.-C. STATION AND ROTARY-CONVERTER SUBSTATION

13. Manhattan Elevated Railway.—Fig. 11 shows the general scheme of distributing current for the Manhattan Elevated Railway, of New York. Current is generated in one large central station by revolving-field, three-phase alternators direct-connected to 8,000-horsepower engines. The use of the revolving-field type of machine enables the current to be generated at 11,000 volts in the machine. It is distributed by means of heavily insulated lead-covered cables, run in underground conduits, to a number of substations, and there passed through stationary transformers that step down the voltage. The rotary converters change the alternating current to direct current at about 625 volts, and from the substations it is supplied to the cars by means of feeders and third rails. The track, ground, and return cables transmit the current to the negative side of the rotaries. The systems of distribution used by the Metropolitan Railway Company, of New York, and the London Underground are, in general, similar to the system just described.

14. New York Central and Hudson River Railroad.—In Fig. 12 is shown a simplified diagram of the distribution of the high-tension circuits for the electric zone of the New York Central system from two power stations—one at Yonkers and one at Port Morris—to eight substations. Each substation has connected to it at least two high-tension feeders and each may be supplied with alternating current from either power station. The lines are so disposed that no ordinary accident can cut off the power supply of a sub-

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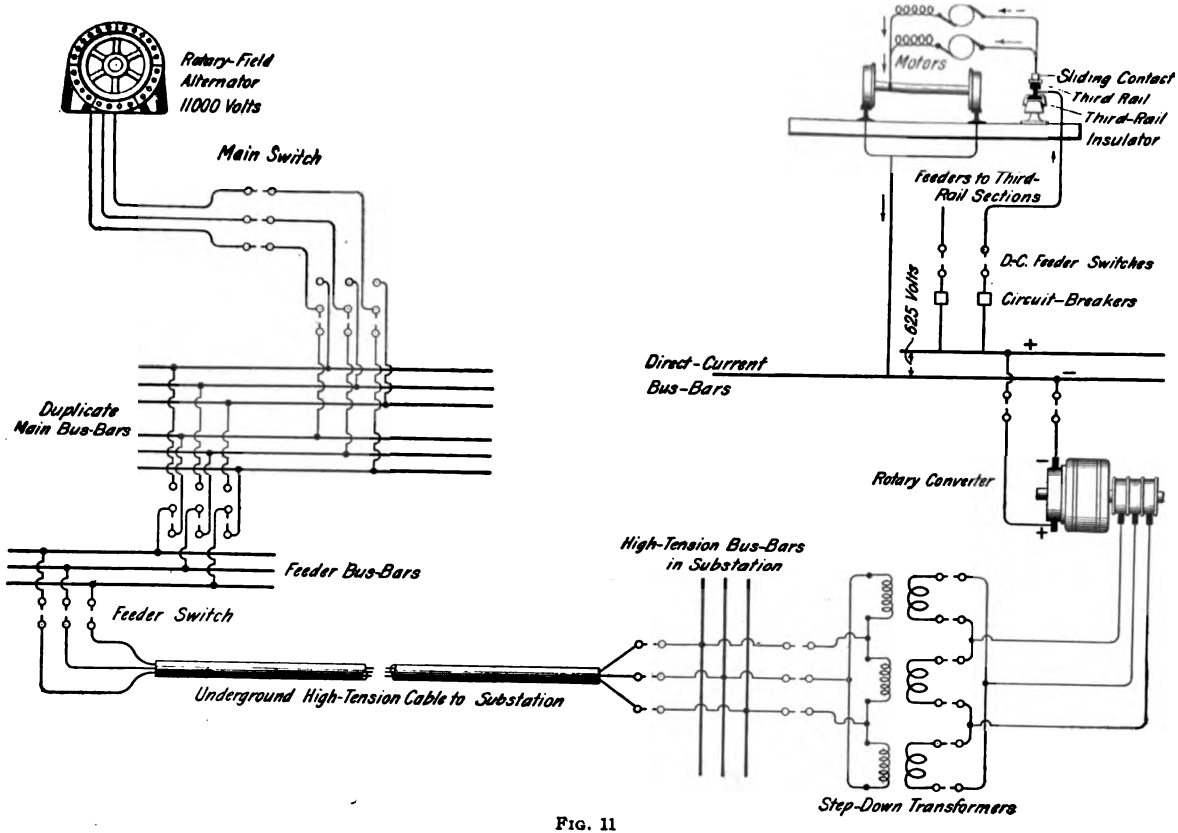

FIG. 11

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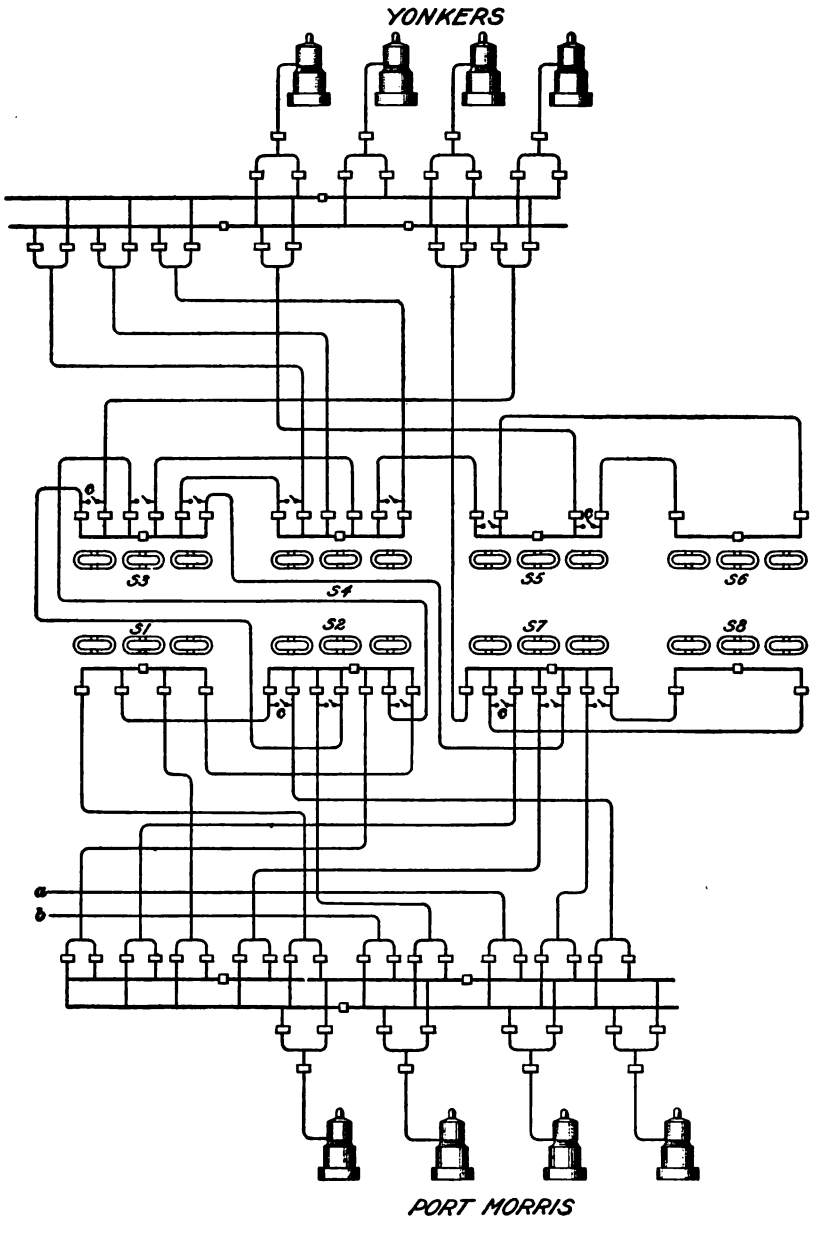

FIG. 12

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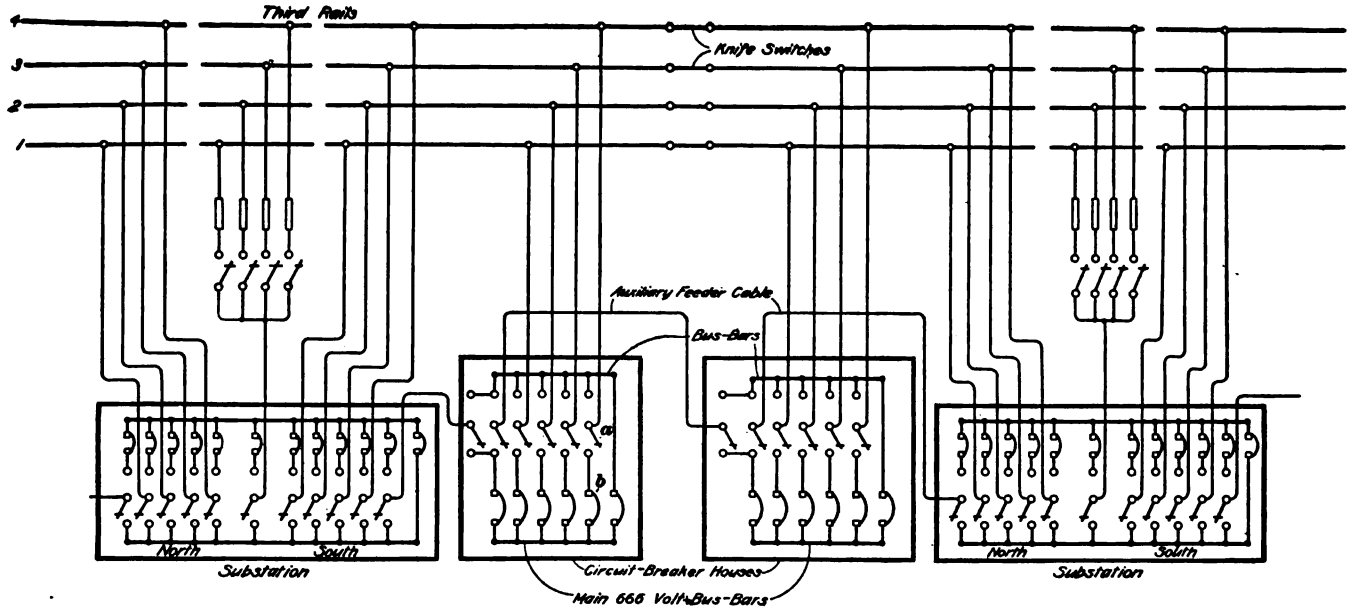

FIG. 13

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station. The transmission voltage at the power station is 11,000 volts.

Each of the power stations has an initial equipment of four Curtis turbo-generators. In each power station are provided two sets of main high-tension bus-bars, as well as selector switches, indicated by the small rectangles, in order that either the generators or the feeders may be connected to either bus-bar. Each generator has an additional set of main oil switches, which is in series with one or the other of the sets of selector switches. To avoid a complication of wires, single lines in Fig. 12 represent either three-phase bus-bars or three-phase circuits, the general connections of the duplicate main bus-bars being much the same as those shown in Fig. 11. Each small rectangle in Fig. 12 represents a set of three oil switches. Feeders *a*, *b* are power feeders for the Grand Central station yard.

Special tie-switches *c* are connected to several of the feeders in order that, if so desired, a high-tension current entering a substation by one feeder can by-pass the substation and feed the next substation directly without going through the high-tension bus-bars of the first substation. The bus-bars of both the substation and the power station may be divided into sections by the switches indicated on them by small squares.

15. The system of connecting the direct-current feeders leading from the substations and circuit-breaker houses to the third rails is shown diagrammatically in Fig. 13. Two circuit-breaker houses are located between each two adjacent substations, except in the case of substations Nos. 1 and 2, between which there are three. One or more auxiliary direct-current feeders connect the substations and the adjacent circuit-breaker houses. In case of trouble at one substation, current may be furnished to the third rails normally controlled by that substation from the other substation through the auxiliary cables, switches *a*, and circuit-breakers *b* in the circuit-breaker houses. The circuit-breakers open automatically in case of overload.

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The third rails are divided into sections, so that in case of disorder on one third rail, one section of the third rail may be disconnected, or killed, without interfering with the action of the other section. Opposite each substation is an 800-foot section of the third rail that is separately fed by the substation. If trouble occurs on one of the main sections on either side, this isolated section may be killed, so as to prevent a train from bridging between the third rails on the main sections.

The circuit-breakers and switches in the substations and circuit-breaker houses are so arranged that they may be operated by small motors, the control switches of which are located in the substations and in some cases in the yard. The circuit-breakers and switches may thus be opened or closed by operating these remote control switches. The direct-current bus-bar potential is 666 volts. The substations are provided with storage-battery equipments of sufficient capacity to operate the maximum train load for their section for about ½ hour.

A.-C. STATION WITHOUT SUBSTATIONS

16. New York, New Haven, and Hartford Railroad. Electric traction is employed on a portion of the system of the New York, New Haven, and Hartford Railroad Company. The electric locomotives used to draw the trains in the electric zone are equipped to operate with either direct current or single-phase alternating current. The trains run from the Grand Central Station to Woodlawn, N. Y., a distance of 12 miles, on the tracks of the New York Central and Hudson River Company, which are equipped with direct-current supply; from this point the 11,000-volt, single-phase, alternating-current supply of the New York, New Haven, and Hartford Railroad Company is used.

The power station at Cos Cob, Conn., contains Westinghouse-Parsons, three-phase, 11,000-volt, turbo-alternators of large capacity. The alternators supply single-phase current for the railroad and three-phase current for other power pur-

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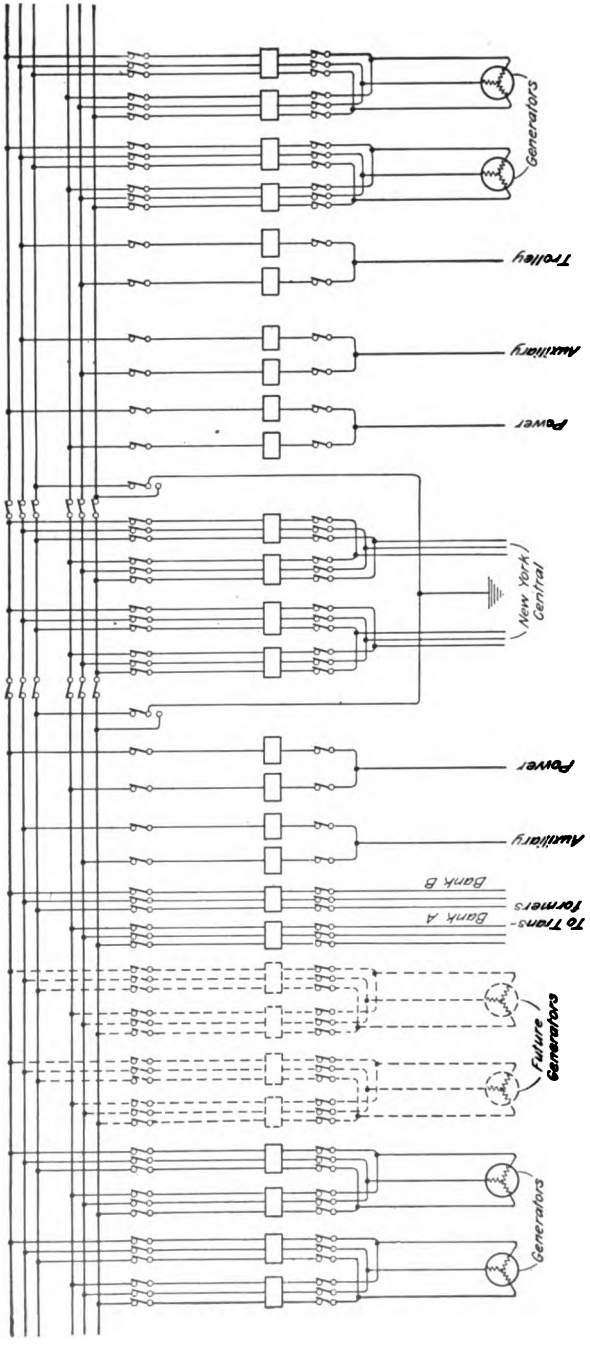

FIG. 14

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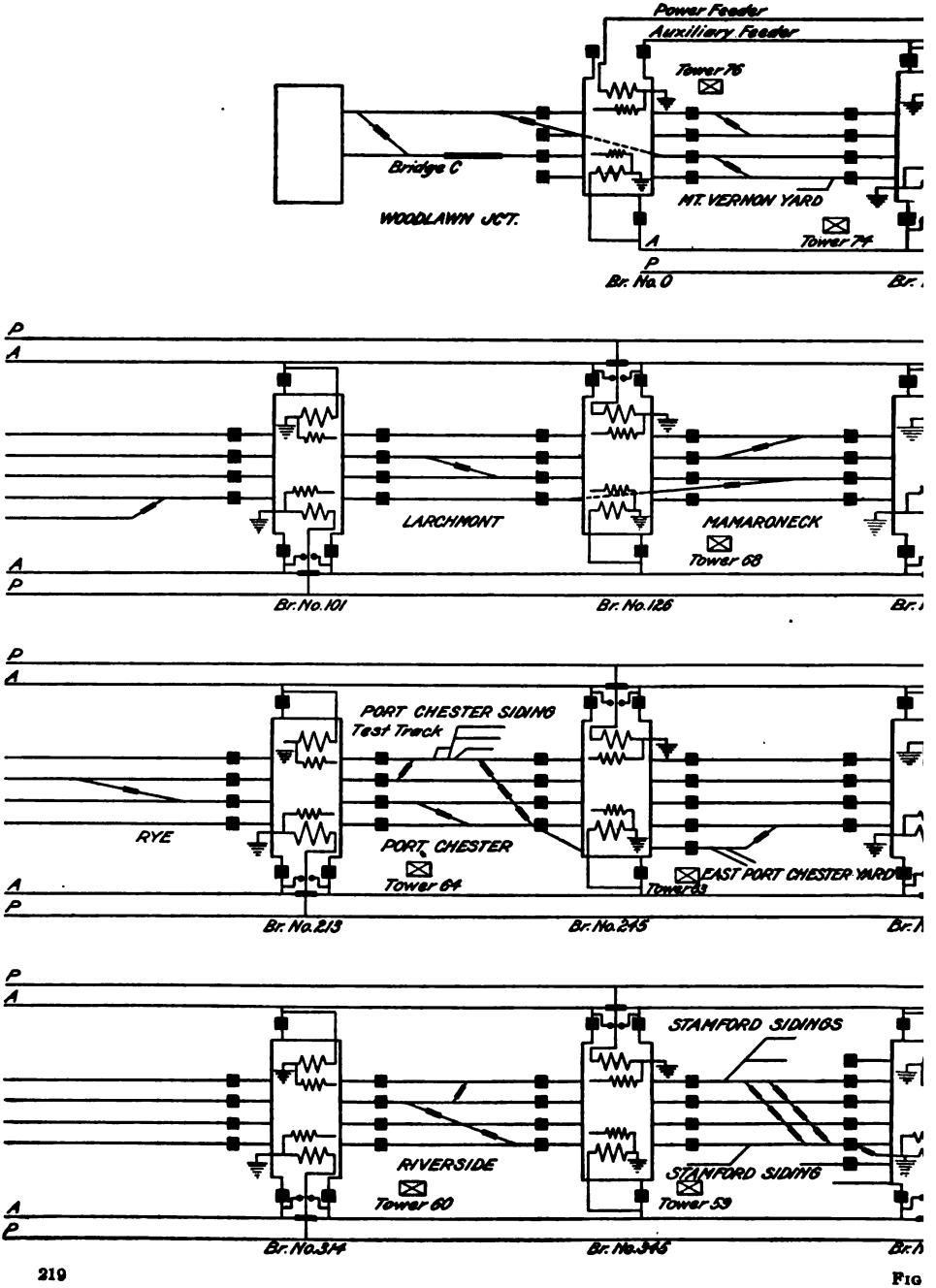

Fig

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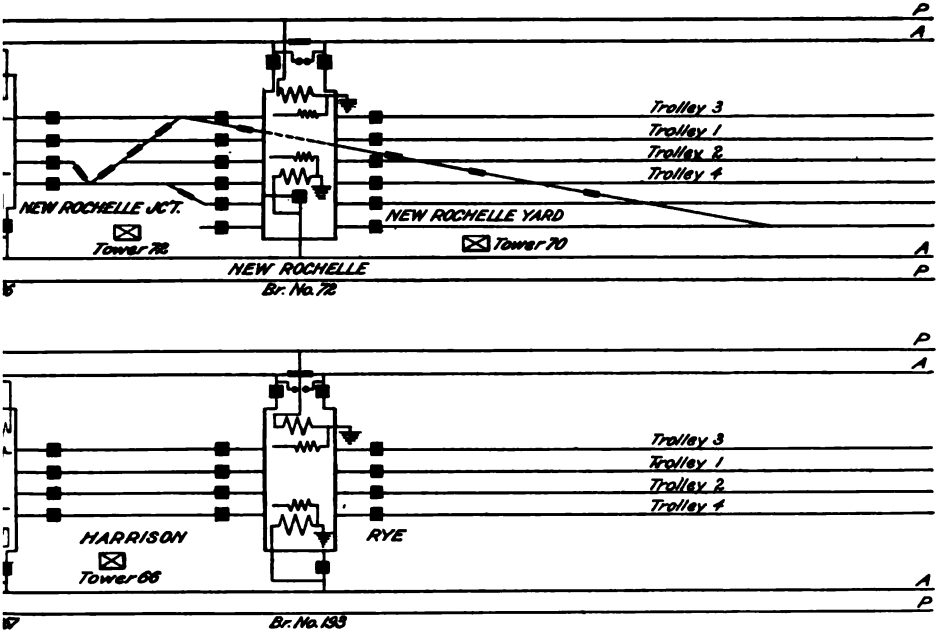
JUNCTION TO STAMFORD



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poses. A simplified diagram of the high-tension connections in the power station is shown in Fig. 14. By means of duplicate sets of sectional bus-bars, disconnecting switches, and oil switches, it is possible, in the case of an emergency, to continue furnishing current to the feeders even when a considerable portion of the plant is shut down.

17. The generator voltage of 11,000 volts is applied directly to the trolley-wire system of the railroad, no step-down transformers being used for the railroad work. There are no substations in the electrical zone of this system. The trolley wires are suspended over the tracks and form one side of the single-phase circuit, while the rails and ground form the other side. Current from the trolley wire is conveyed to the apparatus on the locomotive through one or more pantagraph trolleys, which are described in another Section.

The distribution system of the feeders and trolley wires for a distance of 21 miles is shown in Fig. 15. This system is so arranged that sections of trolley wire in which disorder exists may be killed without interfering with the action of adjacent sections. The trolley wires are supported from bridges that extend across the four tracks at suitable intervals. Anchor bridges installed at the ends of sections of trolley serve to bear the stresses caused by the pull of the trolley suspension system. These anchor bridges are also provided with circuit-breaker switches that may be operated by means of remote control switches located in adjacent signal towers.

18. On each side of the roadbed is installed a pair of supplementary feeder wires consisting of an auxiliary feeder *A*, which is connected to the same phase as the trolley feeder, and a power feeder *P*. The auxiliary feeders are connected through oil switches to the bus-bars on the anchor bridges. These auxiliary feeders increase the carrying capacity of the overhead system, but their principal use is to serve as by-passes for the current in case it is desired to cut out any or all of the trolley wires in any section. By means of these auxiliary feeders, the current may be sent

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around the dead section without interrupting the transmission of current to the other sections in the electric zone.

The auxiliary feeder on each side of the roadbed is broken by a section insulator at every alternate anchor bridge; but in such places one oil switch connects the bridge bus-bar and feeder at one side of the section insulator, and another oil switch connects the bus-bar and feeder at the other side. In case of disorder of the auxiliary feeder at one side of the section insulator, the bridge bus-bar may be supplied with current from the feeder at the other side of the section insulator. Current can also be obtained from the auxiliary feeder located on the opposite side of the roadbed.

19. There are two transformers at each anchor bridge. The auxiliary feeder supplies current to the primary of one transformer and the power feeder supplies current to that of the other transformer. One or the other of the secondary coils of these transformers supplies current to operate the motor-driven signals, the remote control system for the oil switches on the bridges, and the bridge lighting.

20. The power feeder, which is a comparatively small wire, is connected to a different phase from that to which the trolley and auxiliary feeders are connected. A three-phase circuit may be arranged for connection to three-phase motors by means of three wires, the first connecting to the auxiliary feeder, the second to the power feeder, and the third to the track rail.

21. The trolley wire over every cross-over is divided by one or more section insulators, so that these crossing wires will not interfere with the cutting out of any of the main trolley wires. If it were not for these insulators, some of the main trolley wires would be connected together.

No section of the line can be completely cut out from a single tower, or anchor bridge, but, since each trolley section can be fed from either end of the section, two adjacent towermen must cooperate in order to kill any section of trolley wire between two successive anchor bridges. The towers are connected by a telephone line.

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Any given double section of auxiliary feeder can be killed by opening the oil switches on the anchor bridges by means of the remote control switches in the towers. By a careful study of the switching possibilities of the system outlined in Figs. 14 and 15, its extreme flexibility will be apparent. Under conditions involved by ordinary accidents, it is improbable that the whole system would have to be shut down.

LINE CONSTRUCTION

22. The term **line** has a very broad meaning, but in this Section it is used to refer to the fixed conductor from which the electric locomotive or multiple-unit train directly derives current, together with the support for the conductor, the supply feeders, and the track-return circuit.

Most of the long-distance electric-railway systems are equipped with a third rail as the fixed conductor, while on other systems overhead trolley wires suspended by the single- or double-catenary methods serve the purpose.

On some roads using the third rail as the conductor, there are certain places, usually near repair shops, terminal yards, or on city streets, where it is undesirable or dangerous to make use of the third-rail conductor. In such cases, the overhead trolley wire is sometimes used, being suspended in the manner customary in city-street work.

OVERHEAD-TROLLEY CONSTRUCTION

23. Trolley Wire.—Round **trolley wire** is usually employed for overhead line work if trains are not to be run at high speed. In Fig. 16 (*a*) is shown a round trolley wire held by a soldered ear. It seems to be impracticable to hold a round wire so that the ear of the hanger will offer no obstruction to the trolley wheel passing under it. Accordingly, where high speed is desired, trolley wires having the cross-sections shown in (*b*) and (*c*) are used. These wires are held by clamps, or ears, *a* that fit into grooves in

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the wires. The lower part of the wire is thus left free from obstruction, and there is nothing to cause the trolley wheel to jump from the wire. Fig. 17 shows the trolley wire and ear of Fig. 16 (*c*) to better advantage.

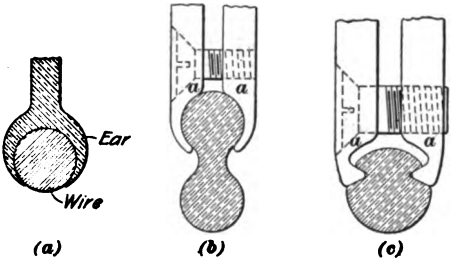

FIG. 16

The wire is usually made of hard-drawn copper, or in case great strength is desired, it is sometimes made of phosphor-bronze. The trolley wire is usually made in sizes from No. 0 to No. 0000 B. & S. gauge.

24. Hangers.—The **hangers** for suspending the trolley wire are made in a great variety of designs, but in general

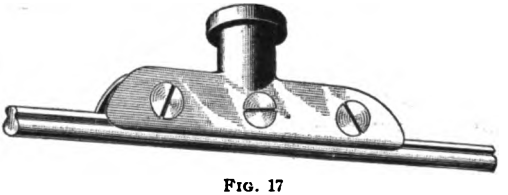
FIG. 17

they consist of three parts, namely, a *casting*, or *body*, that is held by a span wire stretched between poles on opposite sides of the roadbed or supported from a side bracket fastened to a pole, an *ear* that either grips or is soldered to the

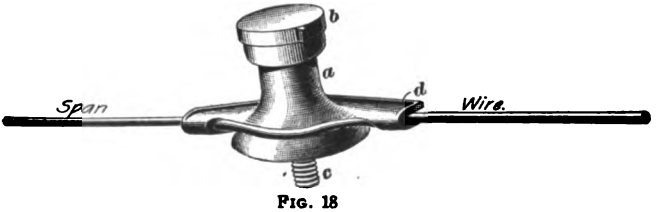

FIG. 18

trolley wire, and an *insulating material* that separates the ear from the casting.

In Fig. 18 is shown a common form of hanger with the ear removed. The main casting, shown at *a*, is provided with a

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grooved extension *d*. The span wire passes through *d* and around *a*, thus holding the hanger in place. The upper part of the bolt *c* is bedded in molded insulating material, and the casting is covered with a metal cap *b*. The ear, to which the trolley wire is fastened, screws on *c*.

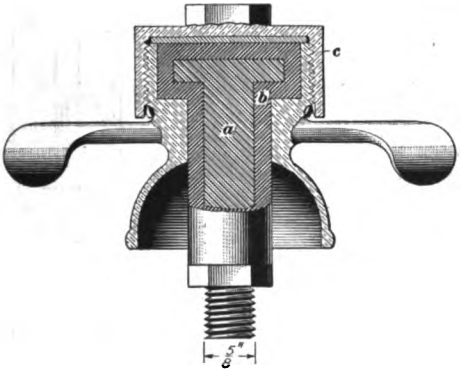

FIG. 19

Fig. 19 shows a sectional view of a hanger very similar to the one shown in Fig. 18. The bolt *a*, Fig. 19, with its molded insulation *b*, is held firmly in place by the screwcap *c*; it can be easily removed, however, by unscrewing the cap.

The metal castings for overhead fittings are made either of malleable iron or of brass. The ears, when intended to be soldered to the line, are made of brass; those designed to clamp on the wire are usually made of malleable iron.

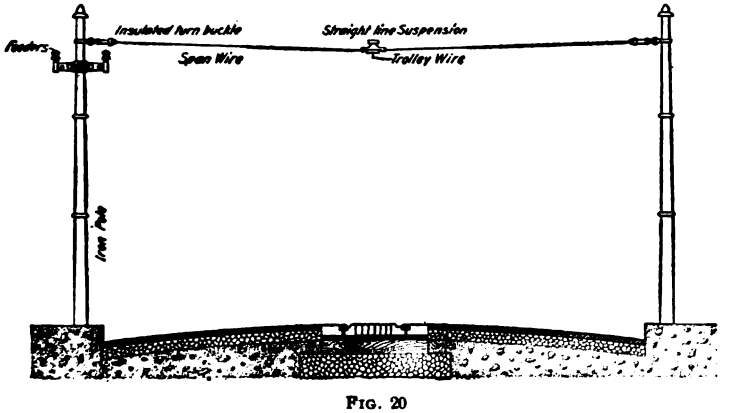

FIG. 20

25. Methods of Supporting Trolley Wires.—In Fig. 20 is shown a form of suspension known as the span-

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wire construction. A span wire is supported from poles located on opposite sides of the roadbed, or street, and the trolley wire is suspended from the span wire by means of an insulated hanger. As indicated in the figure, feeder cables may be carried on cross-arms attached to the poles on one side of the roadbed.

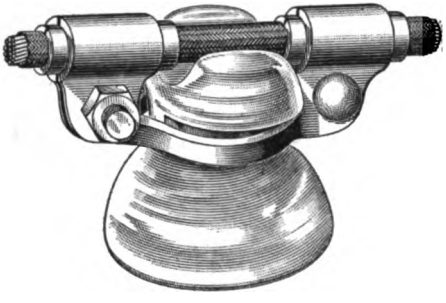

FIG. 21

A form of feeder insulator is shown in Fig. 21. These insulators are screwed on pins mounted on the cross-arms of the poles, and the feeder cables are held in the grooves at the top portion of the insulators by means of metal clamps. With some types of insulators, the cables are held in position by tie-wires.

26. One method of connecting the feeder to the trolley wire is shown in Fig. 22. A piece of solid weather-proof feed-wire is tapped on the feeder and is fastened to the strain insulator *a* at point *c*. The other end of the feed-wire is attached to one end of the strain insulator *b*. The insulation is removed from the feed-wire at the point where the trolley-wire hanger is attached. The hanger has a solid brass bell, without the usual insulation, and is soldered to the copper span wire. Current from the feeder may thus flow to the trolley wire.

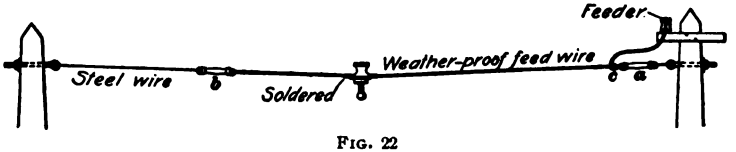

FIG. 22

In order to make the trolley wire conform to curves in the track, it is pulled into position by span wires. These wires are insulated by strain insulators and are fastened to several points on the curved wire.

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27. A form of **bracket construction** is shown in Fig. 23. In this construction, the hanger and the trolley wire are supported from a short span wire attached to the horizontal arm of a bracket. This bracket, in turn, is fastened to a pole placed at one side of the roadbed. The pole may be made either of wood or of iron.

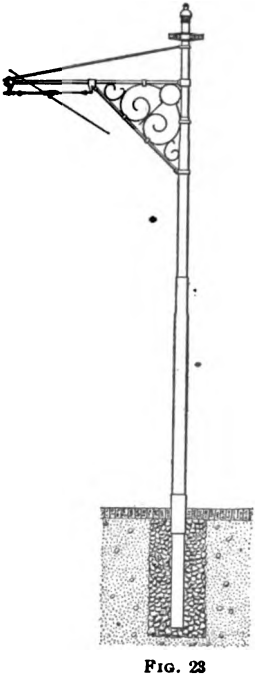

FIG. 23

THIRD-RAIL CONSTRUCTION

28. Location of Third Rail.— For interurban and elevated-railroad work, a construction more substantial than a trolley-wire system is required, because the train speeds are high and the currents to be transmitted are large. In the **third-rail system,** the fixed conductor is an iron rail, called the **third rail.** This conductor is usually mounted at one side of the track, and contact is made with it by means of a sliding shoe carried on the car. The rail is mounted on special insulators and is generally raised somewhat above the other rails. Feeders from the power station connect to the third rail; the regular track rails constitute the return circuit. At grade crossings, the third rail is omitted, as the momentum of the car is sufficient to carry it over the road and into contact with the next length of conductor rail. In the case of a train composed of motor cars, the contact shoes on the first car will make contact with the forward section of the third rail before the shoes on the rear cars have left contact with the other section of the third rail. The third rail, when unprotected, can be used only where there will be no liability of persons coming in contact with it. This system is a ground-return system, in which the overhead trolley wire is replaced by the third rail.

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29. Fig. 24 shows a typical third-rail construction. A plan view is shown at (*a*), an end view at (*b*), and a side view at (*c*). The third rail *r* is, in this case, an ordinary T rail. The rail shown is made in 30-foot lengths and weighs 80 pounds to the yard. It is supported on reconstructed granite insulators *a* located on every fifth tie, which is about 2 feet longer than the other ties.

30. Third-Rail Insulators.—The third rail should be thoroughly insulated from the track rails and ground by

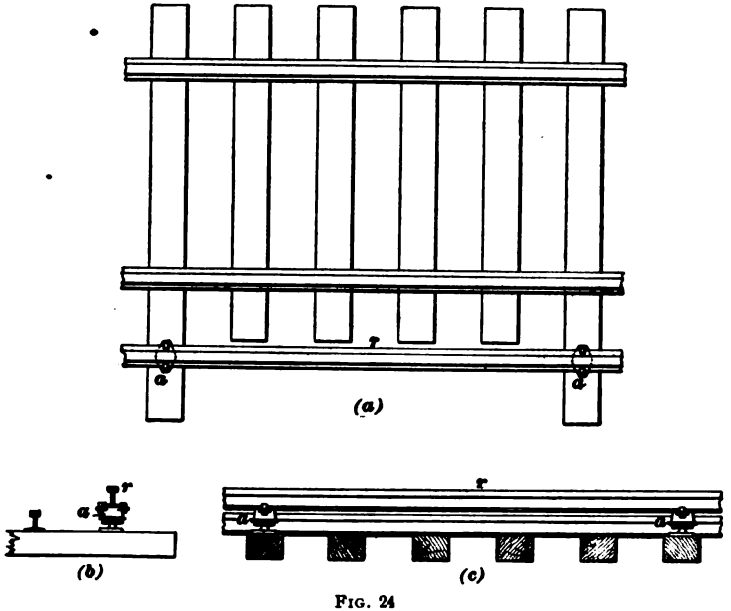

FIG. 24

being mounted on suitable insulators that are strong mechanically and that allow the conductor rail freedom for expansion and contraction. Third-rail insulators have, in many cases, been made of specially treated wood provided with an iron cap for the rail to rest on, but in the best construction, special insulating material, such as *reconstructed granite*, is used. Fig. 25 shows three common types of insulators in which the insulating material is reconstructed

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granite. In (*a*) and (*b*), the rail rests on an iron cap and is prevented from moving sidewise by means of lugs; in (*c*), the rail rests on the granite block and is restrained sidewise by special castings held by a bolt passing through the molded granite. All fastenings should allow a certain amount of up-and-down play; the weight of the rail is amply sufficient to hold it in place, and if it is too tightly fastened, undue stresses will be thrown on the insulators.

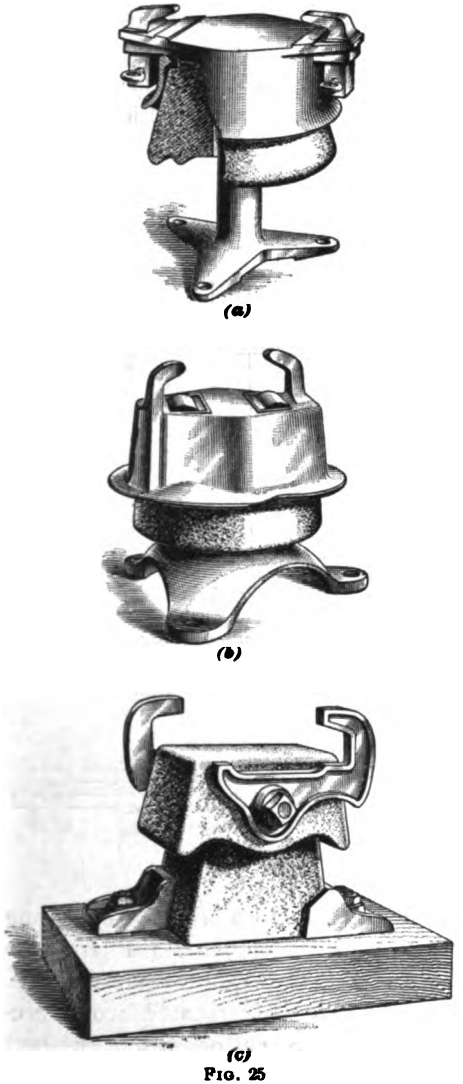

FIG. 25

31. In Fig. 26 is shown a third-rail insulator the top casting of which is provided with two vertical retaining lugs. Each of these lugs is provided with a rib that fits into corresponding notches cut into the base of the third rail. This insulator is used for anchoring the third rail in position and thus preventing it from traveling, which is sometimes brought about by expansion and contraction of the rail, due to temperature changes,

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the grade on which the rail is installed, vibration, and other causes.

32. Protection of Third Rail.—On many roads, the third rail is not protected in any way, but there is a demand for protection of some kind that will make it difficult for accidental contact to be established between the third rail

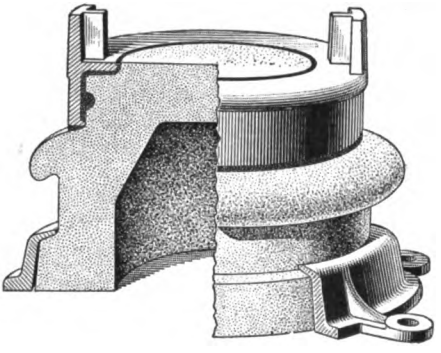

FIG. 26

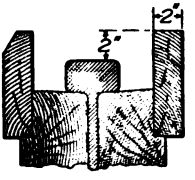

FIG. 27

and the ground or the track rails; also, protection is desirable to prevent the accumulation of ice or snow on the rail. Fig. 27 shows a simple method of protection used on a number of elevated roads. Planks are run parallel to the rail and project about 2 inches above the rail head; anything dropped across the rail is prevented from making contact by the projecting planks. This method, however, does not protect

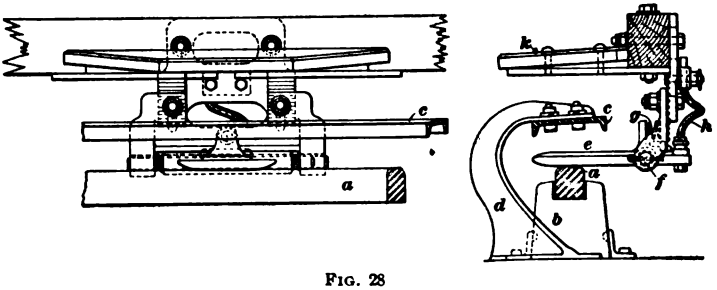

FIG. 28

the rail from snow or sleet, nor does it afford so great a measure of safety as the plan shown in Fig. 28. In this method, the conductor rail *a* is supported on reconstructed-granite insulators *b* and is covered by a channel iron *c*

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fastened to brackets *d* that rest on ties projecting about 18 inches beyond the regular ties. The car shoe *e* is in the

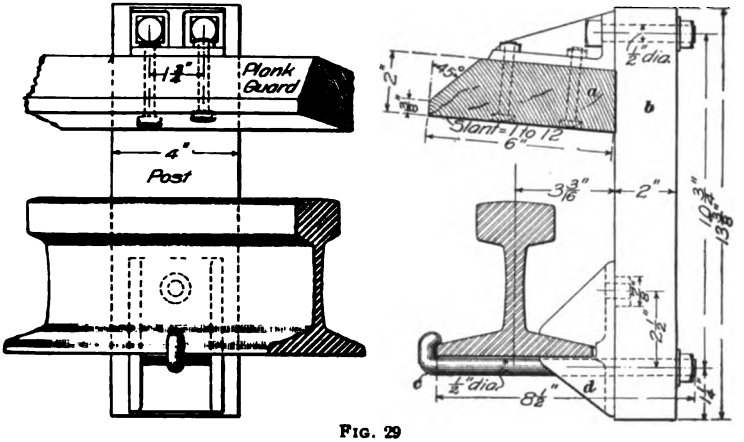

FIG. 29

form of a flat plate hinged at *f* and is held in contact with the rail by a spring *g*. A flexible cable *h* connects the shoe to the main trunk wire running to the controlling apparatus. A projecting wooden guard *k* prevents accidental contact with the parts of the shoe. With this construction it is almost impossible for any one to step on the third rail or for pieces of metal to drop across it and the track rails, thereby causing a short circuit.

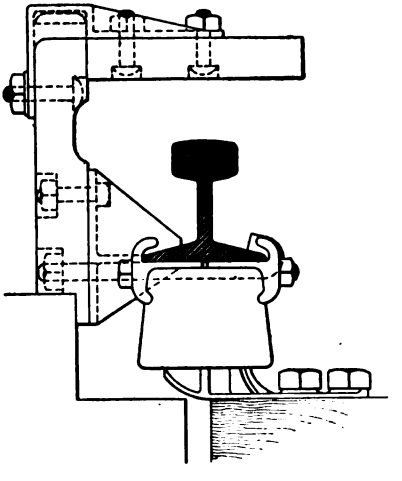

FIG. 30

33. A modification of the method just described is shown in Fig. 29, which illustrates the method of rail protection used on the Wilkes-Barre and Hazleton road. A very similar method is used on the New York subway,

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and in both cases the style of shoe shown in Fig. 28 is employed. The guard consists of a 2-inch pine plank *a*, Fig. 29, fastened to $2'' \times 4''$ oak posts *b*, as shown. The posts are supported from the foot of the rail by clamping them by means of a special bolt *c* and a bearing casting *d* formed to fit the foot of the rail. The construction as a whole is much cheaper than that shown in Fig. 28 and affords protection that is equally as good. Fig. 30 shows the arrangement of the third-rail guard used on the New York subway.

34. The type of protected third rail used in the electric zones of the New York Central and Hudson River Railroad

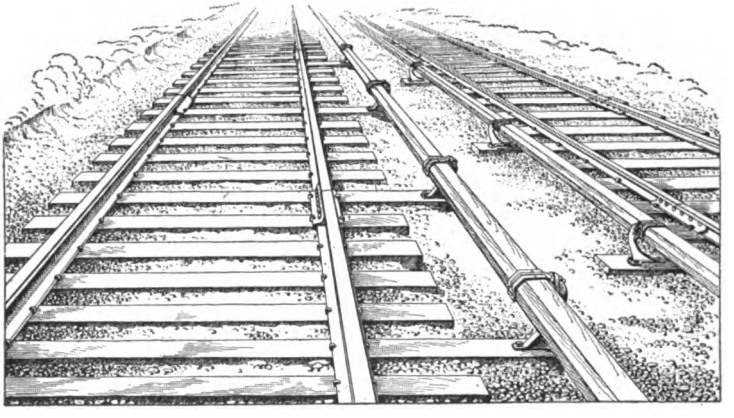

FIG. 31

and the West Shore Railroad is shown in Fig. 31. The rail is of the bullhead, under-running type. The car shoes are pressed upwards against the lower surface of the rail by shoe springs.

The method of supporting the third rail is shown in greater detail in Fig. 32. The iron bracket *a*, located at intervals of 10 feet, supports the semiporcelain insulator blocks *b* that fit around the third rail *c*. A steel hook bolt *d* passes around the insulator and through a lug on the top of the bracket. Lugs on both the bolt and the bracket fit into

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vertical and horizontal grooves in the insulator blocks and thus hold these blocks in position.

The rail between the brackets is first covered with flexible-fiber sheathing and further protected by means of a top

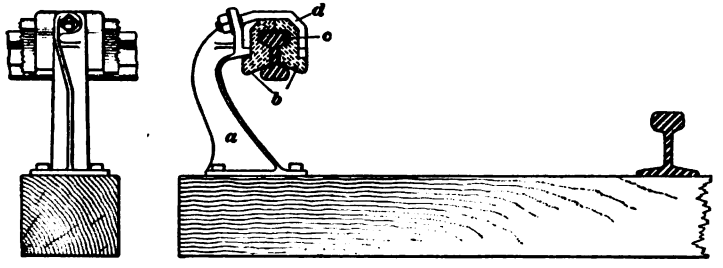

FIG. 32

strip and two side strips of yellow-pine boards. With this thorough protection, there is but slight chance of an accidental connection between the third rail and the ground or the track rail.

The third rail is anchored at frequent intervals by means of bolts that pass through the rail and wooden insulator

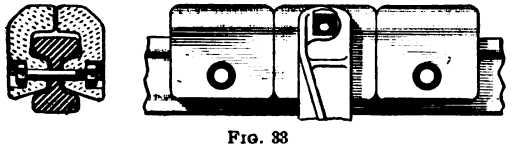

FIG. 33

blocks mounted on either side of a regular semiporcelain insulator, as shown in Fig. 33.

RAIL BONDS

35. Types of Rail Bonds.—In order to transmit current through long lines of third rail or of track rail without undue loss, it is necessary that the connections between adjoining rails be of good conductivity. Flexible copper strips or wires, called **bonds**, are commonly used to connect the rail ends. There are many types of bonds and many methods of connecting them to the rails. In one type of terminal, plugs

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of copper having a soft-iron center are connected to the ends of the flexible portion of the bonds, and these plugs are

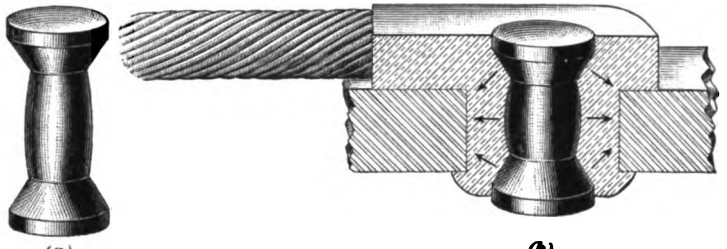

FIG. 34

forced into holes in the rails and then expanded so as to make a tight fit, as shown in Fig. 34. A bond of the compressed-terminal type is shown in Fig. 35.

Bonds with amalgamated contacts are being used successfully. The contact surface on the rail and the surface of the small plates to which the bond wire, or strips, are attached are thoroughly cleaned and covered with copper-mercury amalgam; then the plates are pressed firmly against the rail by means of bolts, or sometimes by means of one of the *fish-plates* used to hold the rails together.

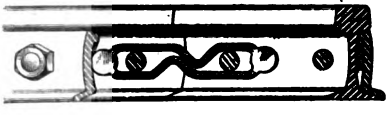

FIG. 35

On many roads bonds composed of copper strips are used. The ends of these strips are welded into solid terminals, which are soldered to the rails. A bond used for connecting the ends of third rails is shown in Fig. 36. The terminals of this bond are long and thus present a large surface of contact between the bond and the rails. The bond is

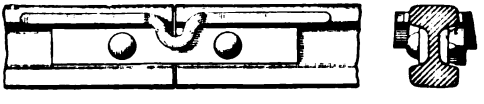

FIG. 36

attached to the upper head of the rail because this is a type of under-running third rail.

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36. Connections of Third Rails at Highway Crossings.—Where a third-rail road crosses a public highway at grade, or where there are turnouts in the track system, it is necessary to make a break in the line of contact rail and to arrange connections between the two sections of rail thus formed by means of either an overhead or an underground cable, usually called a **jumper.** The connection is nearly always made by means of an underground cable, which is much shorter than an overhead one could possibly be.

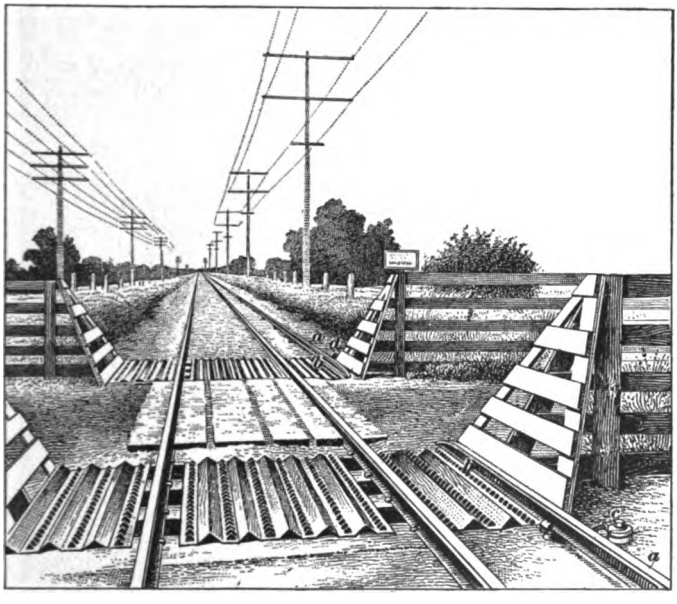

FIG. 37

Fig. 37 shows a typical crossing. The contact rail *a* is provided with cast-steel, inclined approach blocks *b* that allow the shoes to glide on to the rails without shock. A cable is attached to the rail at *c*, and it is carried underground to *d*, where it connects to the rail again, thus preserving the continuity of the conducting system. The cable should have a cross-section equivalent, in carrying capacity, to that of the rail. For this purpose, 1,000,000-circular-mil, lead-covered, paper-insulated cable is often used.

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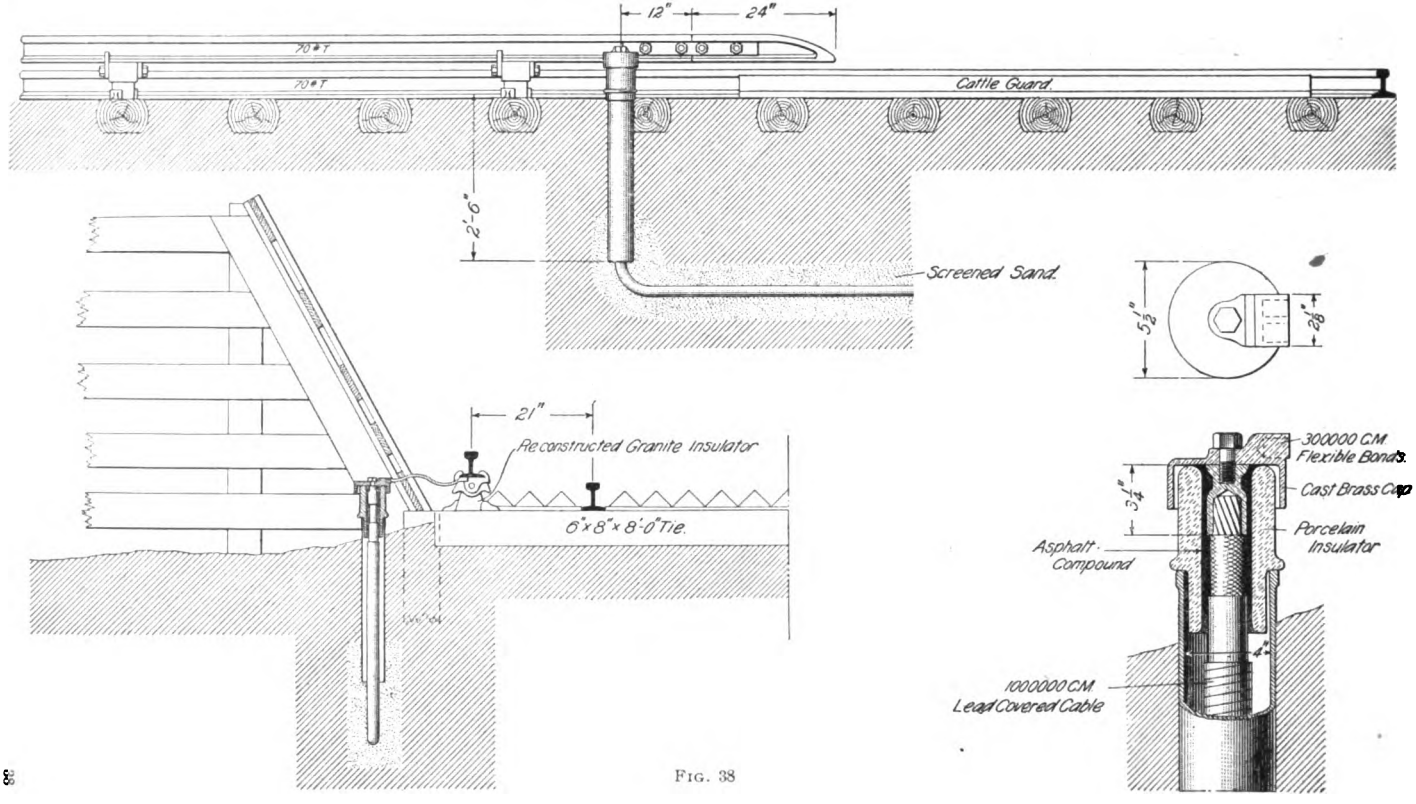

FIG. 38

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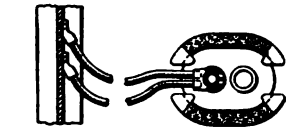
37. Various methods are used for running the cable. One very common plan is to incase it in tile and fill the tile, at the ends, with insulating compound that will prevent water from entering. The cable must be thoroughly insulated from the ground, otherwise there will be leakage and consequent electrolytic action that will eat away the cable in course of time. Fig. 38 shows a method used on a third-rail road in Michigan, the cable in this case being carried through a heavy porcelain insulator set in a cast-iron pipe. The strands of



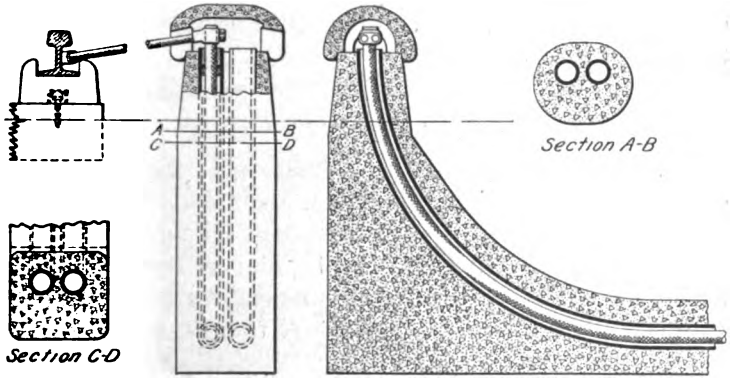


FIG. 39

the cable are soldered into a terminal casting, and after the lower part of the insulator has been plugged with oakum, the space is filled with insulating compound that prevents moisture from entering the paper insulation of the cable. The cable has a lead sheath covered with jute treated with asphalt. A brass cap is bolted to the cable terminal, and from it two 300,000-circular-mil flexible bonds connect to the rail. The cable after it leaves the pipe is bedded in screened sand. With this construction there is little danger of electrolytic action on the cable sheath.

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38. A later type of third-rail jumper used on the West Jersey and Seashore Railroad is shown in Figs. 39 and 40. The cable is drawn into a black, bituminized, fiber tube, which is laid in solid concrete. A concrete or a terra-cotta cap protects the top of the cable, and flexible leads connect the cable to the third rail. In case it is desired to have independent jumper cables for the two sets of third rails on a double-track road, another cable can be installed in the second fiber tube.

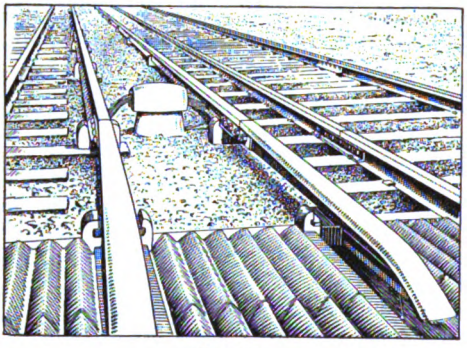

FIG. 40

CATENARY LINE CONSTRUCTION

39. For high-speed, high-potential railway work, the ordinary overhead construction is not suitable. In such construction, the trolley wire sags between supports and would thus cause a sudden lifting and bending of the wire as the trolley passed under it. The insulation of the 500- or 600-volt line construction is insufficient for the high voltages used in alternating-current railway work. To meet such conditions and to provide an overhead system that fulfils the requirement of high-speed railroading, the *catenary line-construction system* was introduced.

SINGLE-CATENARY CONSTRUCTION

40. In the **single-catenary construction,** shown in Fig. 41, a $\frac{7}{16}$-inch, seven-stranded, galvanized-steel cable *a*, called a *messenger cable*, is supported by bracket construction from poles on one side of the track or from span wires between poles on opposite sides of the track. The trolley

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wire *b* is suspended from the messenger cable by means of iron hangers *c* of proper lengths to maintain the wire at a uniform height above the track. The contact shoe of the pantagraph trolley attached to the roof of the car or the locomotive slides smoothly under the wire and will cause it to move but slightly. The messenger cable, being connected electrically as well as mechanically to the trolley

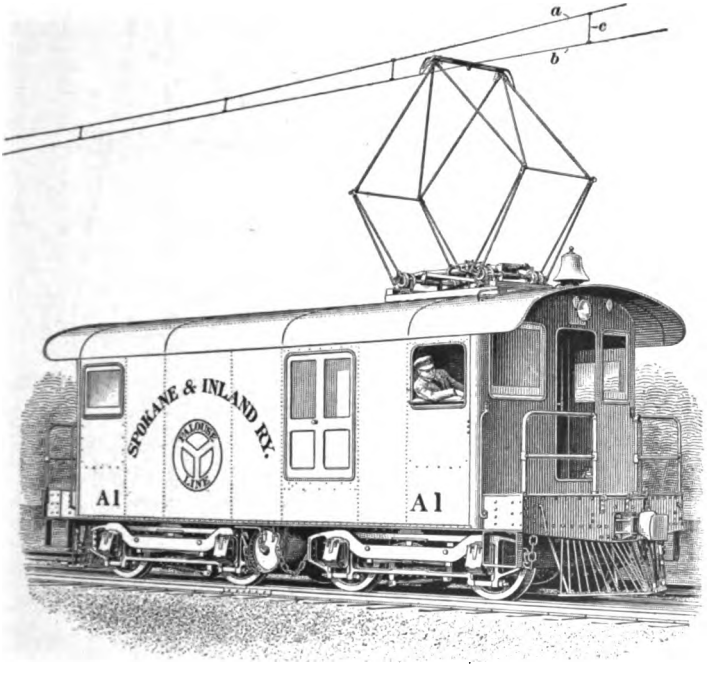

FIG. 41

wire, serves as an auxiliary conductor. Both the cable and the trolley wire are insulated from the brackets and poles by means of either porcelain or wooden insulators.

41. Cross-Span Construction.—A cross-span, single-catenary construction for a straight track is shown in Fig. 42, in which the messenger cable is shown at *a*, the trolley wire at *b*, the hangers at *c*, a T iron at *d*,

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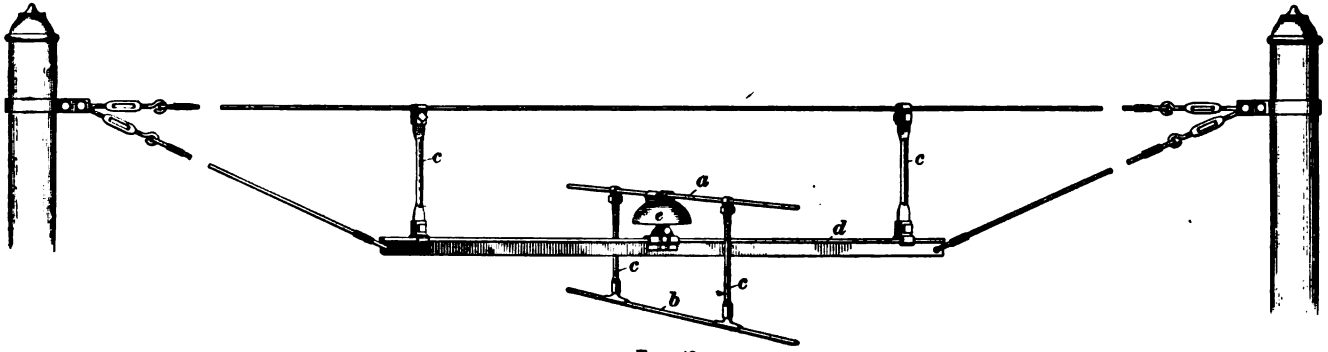

FIG. 42

FIG. 43

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and a large porcelain insulator clamped to the T iron, at *e*. The messenger cable is fastened to *e* by soft-copper tie-

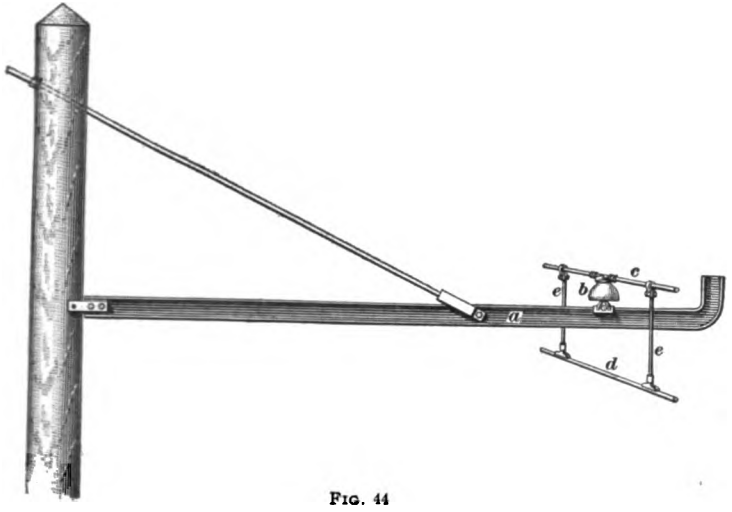

FIG. 44

wires. For curves, a construction similar to that shown in Fig. 43 is used. The trolley wire is held directly under the messenger cable, and wooden strain insulators *a* insulate the messenger cable and trolley wire from the poles.

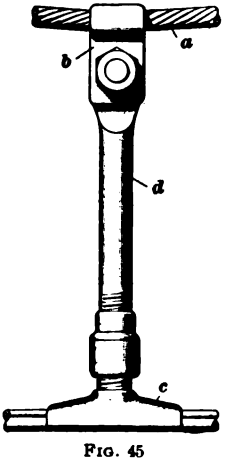

FIG. 45

42. Side-Bracket Construction. **A side-bracket construction** is shown in Fig. 44, in which the bracket arm is shown at *a*, the insulator at *b*, the messenger cable at *c*, the trolley wire at *d*, and the hangers connecting the messenger wire and the trolley at *e*.

The messenger wire sags between the supporting poles, but the trolley wire, being supported by the hangers, maintains almost the same height above the track throughout its length. The trolley wire is supported about 17 inches below the messenger cable at the poles, and

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the distance between the messenger cable and the trolley wire gradually decreases toward the center of the span between the poles.

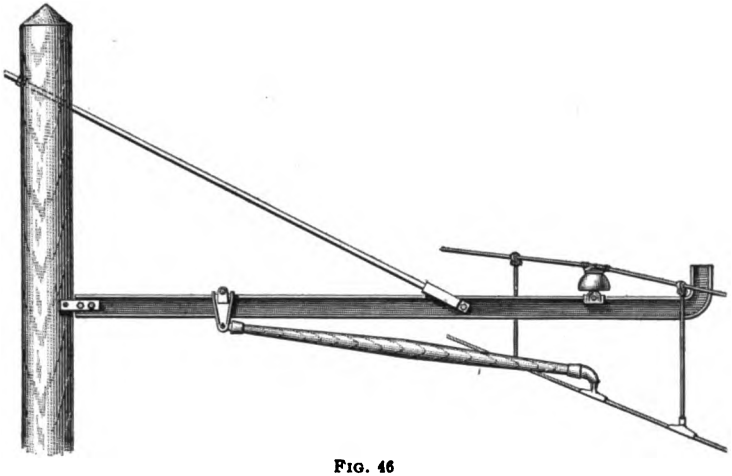

FIG. 46

The type of hanger used for this construction is shown in Fig. 45. The messenger wire *a* is encircled by a clamp *b*.

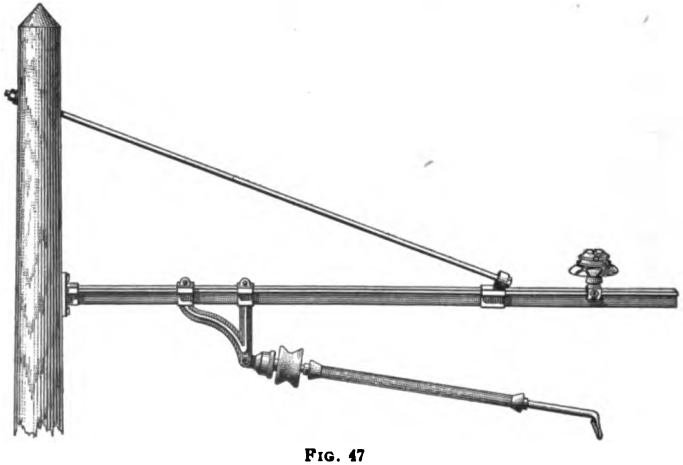

FIG. 47

Another clamp *c* holds the top of the grooved trolley wire, leaving the bottom of the wire unobstructed for the passage

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of the trolley shoe. A length of pipe *d* joins the clamps *a* and *c*. This pipe varies in length, according to the position of the hanger on the span between the poles.

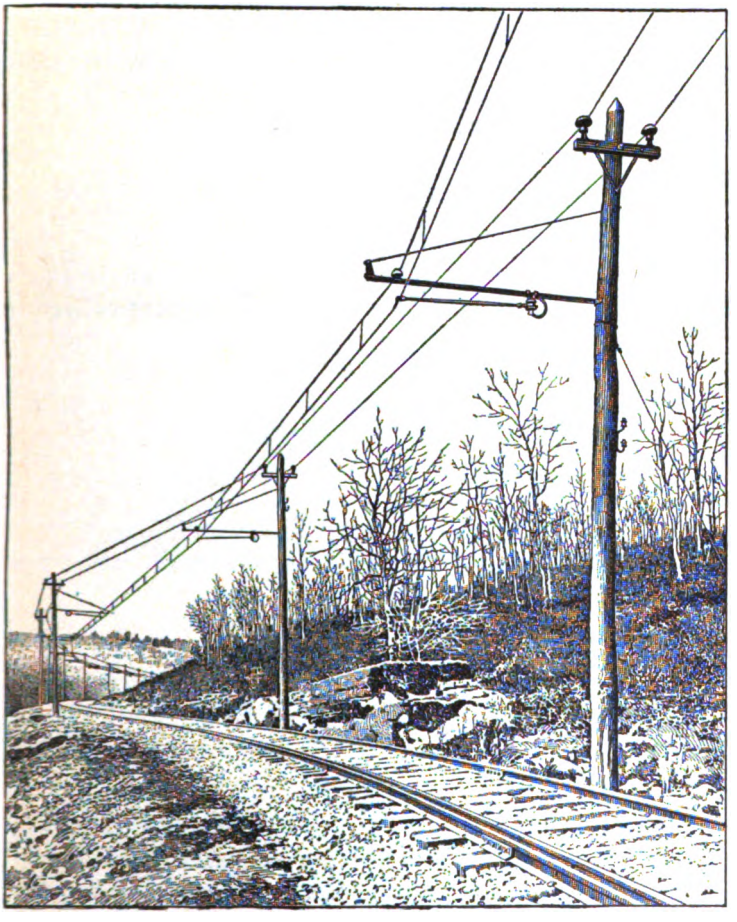

FIG. 48

43. Steady-Strain Bracket.—On curves of large radius, and at intervals of about 440 feet on a straight track, a supplemental rod, Fig. 46, made of hardwood is attached to the bracket. One end of the rod is attached to the

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bracket arm, and the outer end of the rod terminates in a clamp, which is secured to the trolley wire. This serves to keep the catenary structure in an upright position. A bracket thus equipped is called a **steady-strain bracket.** Another, but somewhat similar, construction for the same purpose is shown in Fig. 47. Both wooden and porcelain strain insulators are used in the bracket construction where the electromotive force is above 3,300 volts. In Fig. 48 is shown a portion of a line equipped with a type of bracket similar, in general respects, but differing slightly in details, to that shown in Fig. 46.

44. Location of Trolley Wire.—When an ordinary trolley wheel is to be employed as a current-collecting

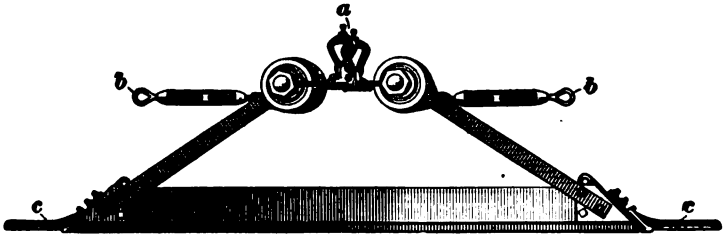

FIG. 49

device, the trolley wire is placed over the center of the track. When a sliding contact shoe is to be used, however, the wire is placed alternately $8\frac{1}{2}$ inches to the right and the left of the center line of the track, so as to distribute the wear on the shoe.

45. Auxiliary Apparatus.—The section insulators, pull-off hangers, etc., used in alternating-current systems, are somewhat similar to those used in ordinary low-tension, direct-current systems, with the exceptions that the insulation provided is much better and that both the messenger cable and the trolley wire are mechanically connected to the devices, as shown in Fig. 49, which represents a section insulator. Clamps *a* are mounted on the T-iron support; the messenger cables are connected at *b*, and the trolley

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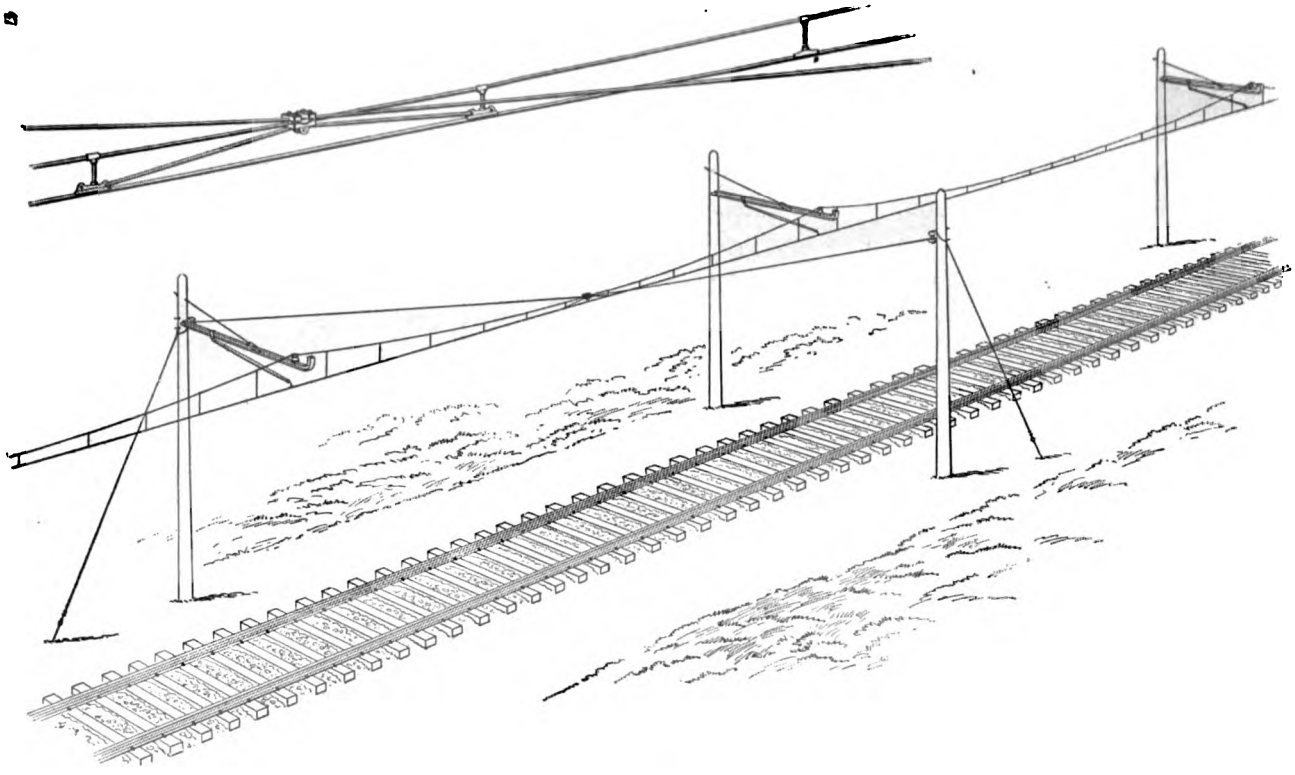

FIG. 50

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wires at *c*. Cylindrical porcelain insulators separate the two sections of messenger cable, and a wooden strip, as shown, separates the two trolley-wire sections.

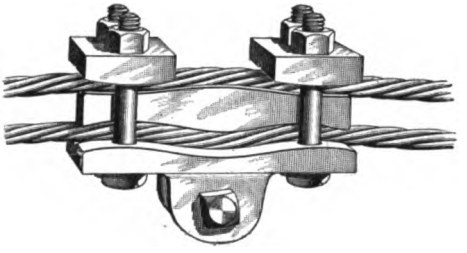

FIG. 51

46. Anchoring the Line.—The line is anchored at suitable intervals, usually at about three points per mile. This is done by attaching an *anchor clamp*, Figs. 50 and 51, to the messenger cable, midway between poles. A second, or anchor, cable is secured to the second groove of the clamp. As shown in Fig. 50, one end of this cable is secured to a strain insulator, similar to the one shown at *a*, Fig. 43, on the nearest regular pole at the left; the other end of the anchor cable is secured to another strain insulator fastened on an extra pole located to the right of the anchor clamp and opposite a regular bracket pole. Both poles carrying the strain insulators should be guyed. The first hanger on each side of the anchor clamp is a pull-off hanger of the type shown in Fig. 52. A short piece of cable fastens the lower part of each pull-off hanger to the projection on the under side of the anchor clamp.

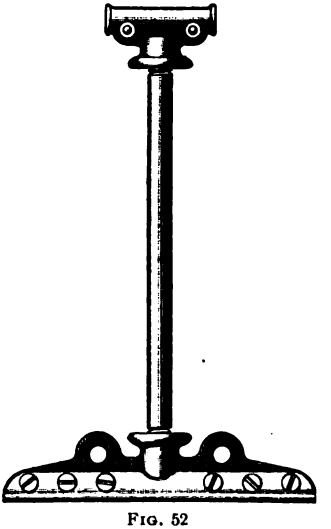

FIG. 52

47. Trolley Frogs.—At turnouts, special forms of bronze frogs are used for connecting the turn-out trolley wire with the main line wire. These *trolley frogs* are either right- or left-handed, depending on the location. They are so constructed as to permit the sliding shoe of the trolley to pass under them without catching. One type of trolley

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frog is shown in Fig. 53. Lugs on the frogs are provided for attaching pull-off wires. These wires are insulated from the poles to which they extend.

FIG. 53

48. Deflector Wires.—To insure that the sliding trolley shoe will pass smoothly over the junction of the main trolley

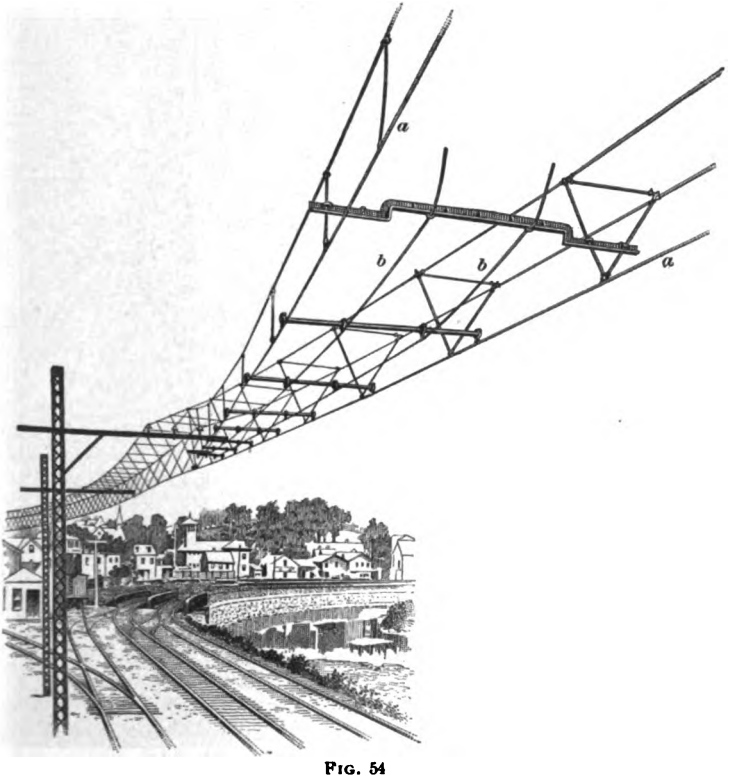

FIG. 54

wire and turnout trolley wire, *deflector wires* are placed in the angle formed by the two wires, as shown in Fig. 54, in

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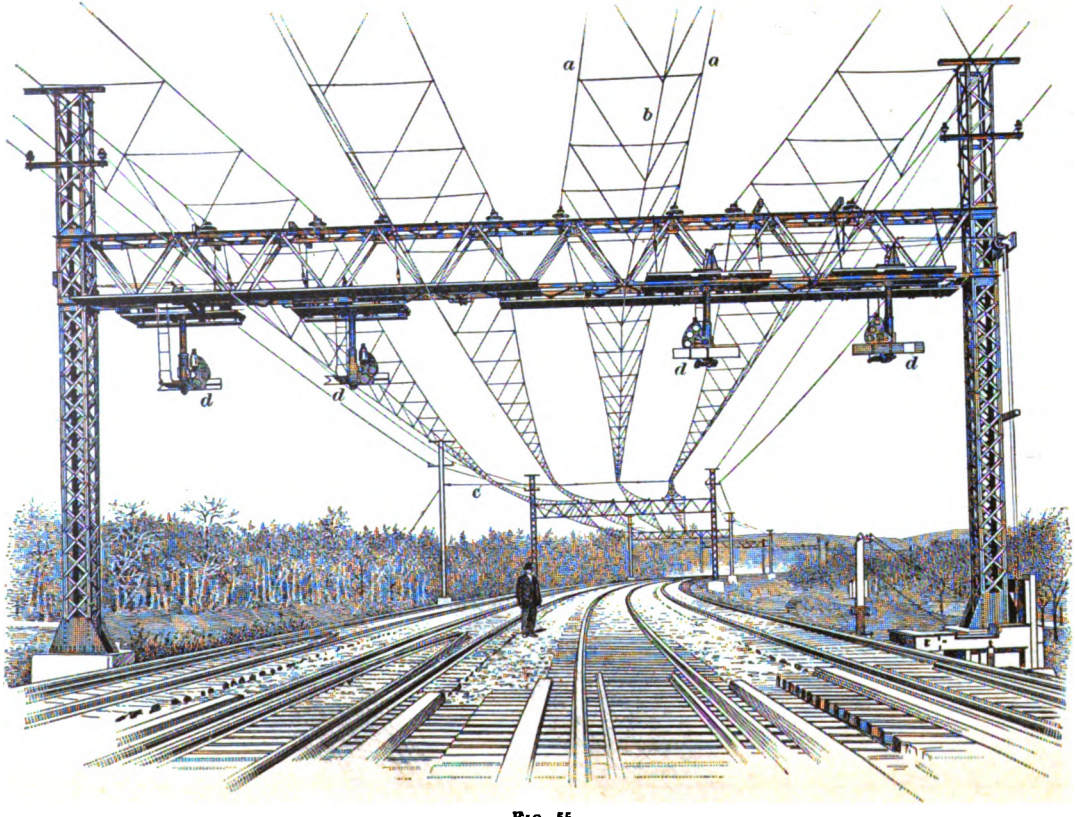

FIG. 55

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which the two trolley wires are shown at *a* and the deflector wires at *b*. The trolley wire under which the shoe is moving is elevated slightly above the other trolley wire by the shoe pressure, and were it not for the deflector wires and the method of mechanically connecting the trolley wires together, which to a certain extent equalizes the elevation of the wires, the shoe might catch in one of the wires as it approaches the frog.

DOUBLE-CATENARY CONSTRUCTION

49. Bridges.—For heavy traffic roads having two or more tracks, a more substantial overhead construction has been developed. Steel bridges spanning the tracks support a **double-catenary line construction.** In Fig. 55 are shown two messenger cables *a* from which the trolley wire *b* is suspended by triangular supports. This method of suspension results in a very rigid line construction. At intervals, anchor bridges are provided to bear the stresses of the line wires. Massive insulators mounted on the tops of the bridges insulate the catenary construction from the bridge structure. A method of deflecting the double-catenary construction to conform to slight curves in the track is shown at *c*. Block signals are shown at *d*. The double-catenary construction may also be supported on bracket arms projecting from poles at one side of the track, as shown in Fig. 56.

50. The double-catenary construction shown in Fig. 55 is the one that was originally used in the electrical zone of the main line of the New York, New Haven, and Hartford Railroad, but a fourth wire, acting as the working conductor, has since been added to the overhead system. The original working conductor was made of copper. It was found that the passage of the pantagraph trolley shoes caused considerable wear on the wire, and that, owing to high temperature, there was enough expansion of the wire between supports to cause some slack. This slack the shoes gathered up in the form of kinks at the hanger points, and these kinks caused

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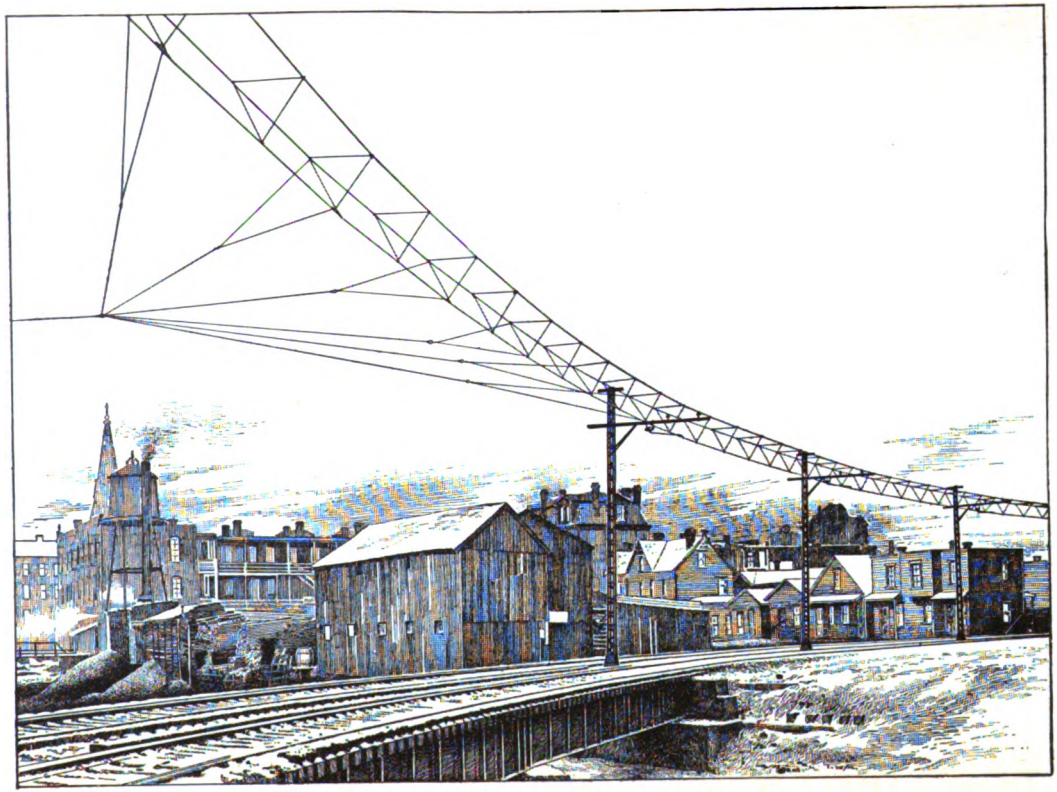

FIG. 56

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sparking at the shoes; also, because of the unevenness of the trolley wire, the wire received very hard blows from the shoes, thus greatly weakening it.

The new working conductor, which is a No. 0000 steel wire, is suspended from the original trolley wire by means of short clips located midway between the triangular hangers, as shown in Fig. 57. A very flexible suspension is thus secured; also, since steel wire is less ductile than copper wire and its length is not changed so much by variations in temperature, kinking is avoided. The wear on the steel wire is very slight.

Adjacent to and under low bridges, double-arm clips con-

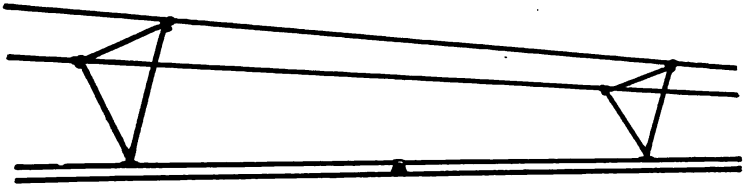

FIG. 57

nected to the hangers support two working conductors in the same horizontal plane, as shown in Fig. 58.

51. Auxiliary Apparatus.—The auxiliary line apparatus of the double-catenary construction differs somewhat from that of the single-catenary construction, because there are two supporting messenger cables for each trolley wire. Each messenger cable is made of steel wire, is $\frac{9}{16}$ inch in diameter, and has seven strands.

The main line insulator used on the intermediate bridges for supporting the messenger cables is shown in Fig. 59. These insulators are clamped to the upper portion of the bridge structure. The porcelain insulator is 15 inches in diameter and about 7 inches high. The catenary cable rests in a groove in the top of the porcelain and is held in position by means of iron clamps fitted with U bolts. One of these clamps is placed on each side of the insulator. A split iron clamp with lead packing surrounds the head of the insulator and is connected to the wire clamps by means of bolts.

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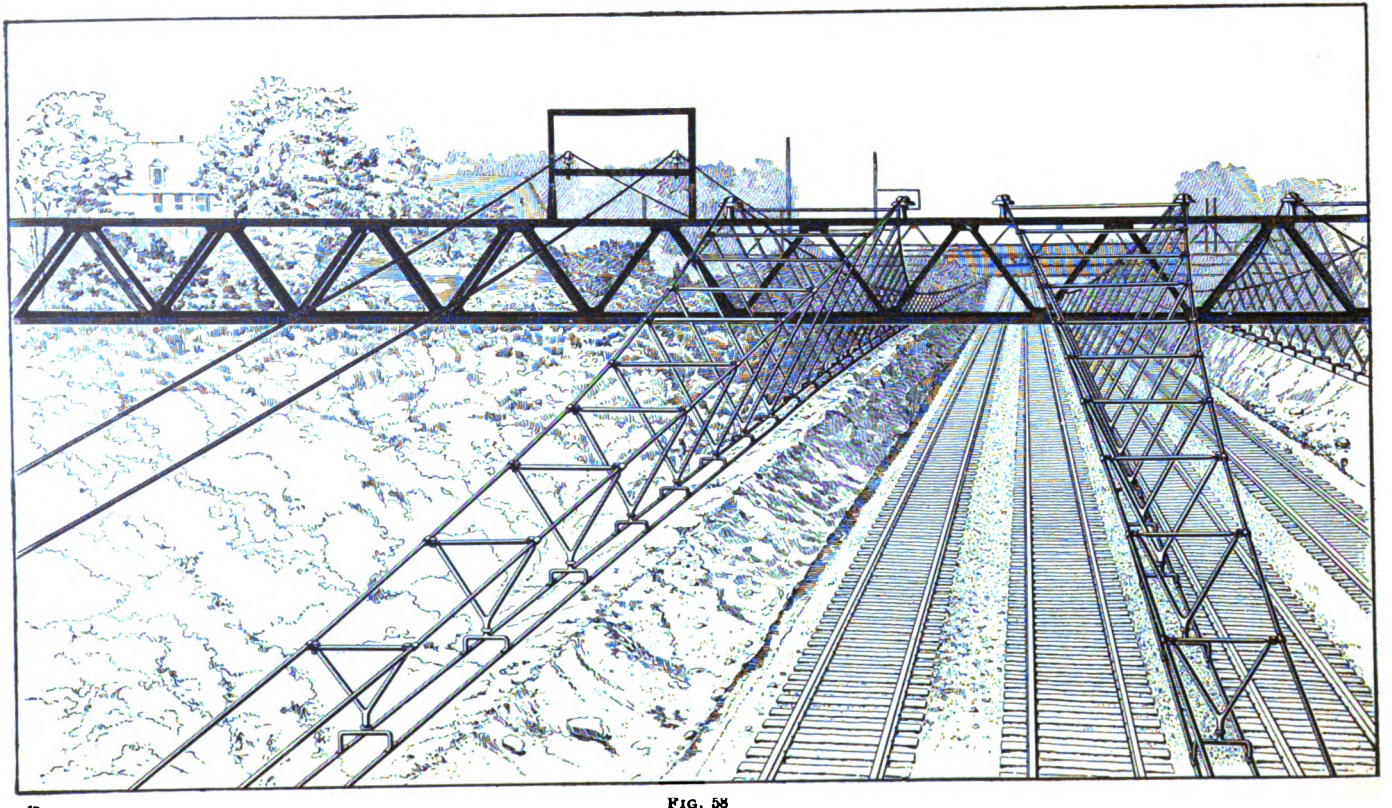

FIG. 58

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52. At the anchor bridges, the messenger cables are dead-ended. The type of strain insulator used for this purpose is shown in Fig. 60. These insulators are suspended

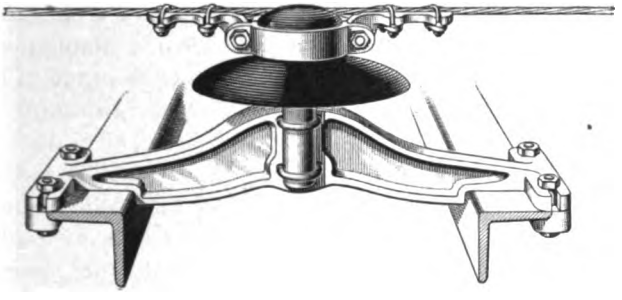

FIG. 59

from the upper portion of the anchor bridges by means of hooks. A turnbuckle connects the ring bolt of the insulator to the messenger cable.

53. The trolley wire at each anchor bridge is also separated into sections. Originally, this was accomplished

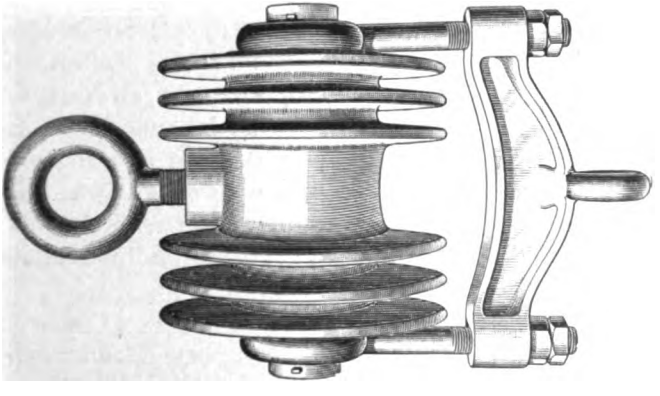

FIG. 60

with the type of trolley section insulator shown in Fig. 61. This device consists of two bronze end castings *a*, to which the ends of the trolley wire are bolted. Two separate parallel

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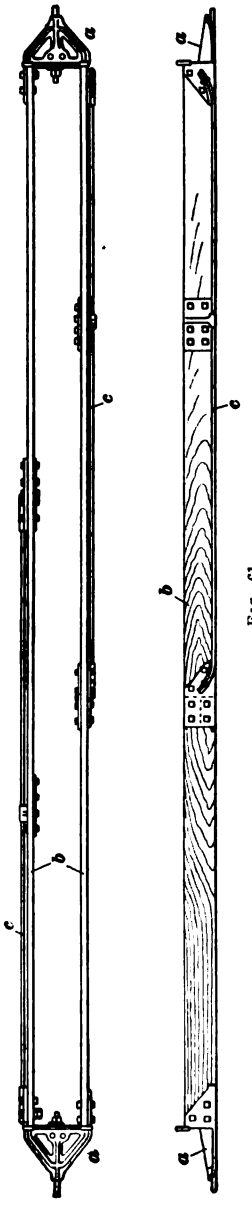

FIG. 61

sections of impregnated hardwood *b* are fastened to these castings, and to these wooden strips are fastened two renewable pieces of trolley wire *c*. These pieces of trolley wire are fastened in such a manner that their ends overlap each other in distance along the track, although the two wires are electrically distinct. By this means, it is possible for the sliding contact on the locomotive to pass from one section of trolley wire to the next without opening the circuit through the locomotive. An effective insulation is provided by the hardwood strips, so that, normally, there is no electrical connection between the ends of the insulator.

It was found that the frame of this section insulator was liable to get out of shape and thus cause severe arcing. In a later development, the end of the trolley wire of one section is suspended parallel to and about 16 inches distant from the end of the trolley wire of the other section. The wires are parallel for some distance, but are carefully insulated from each other.

54. An end view of an anchor bridge is shown in Fig. 62, in which the trolley wires are shown at *a*; the original type of trolley section breaker at *b*; the messenger cables at *c*; the strain insulators for the

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messenger cables at *d*; the circuit-breakers in the trolley-wire circuit at *e*; the bridge bus-bar at *f*; the transformers,

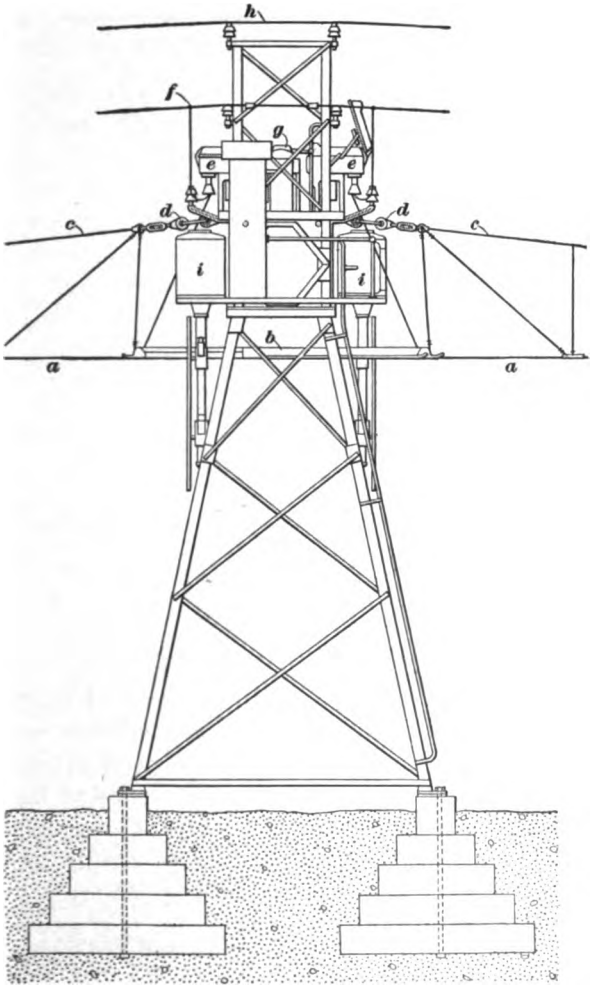

FIG. 62

one of which is at each end of the bridge, at *g*; one of the feeder wires at *h*; and the signal boxes at *i*.

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55. A type of trolley hanger used for double-catenary construction is shown in Fig. 63. In this device, clamps *a*

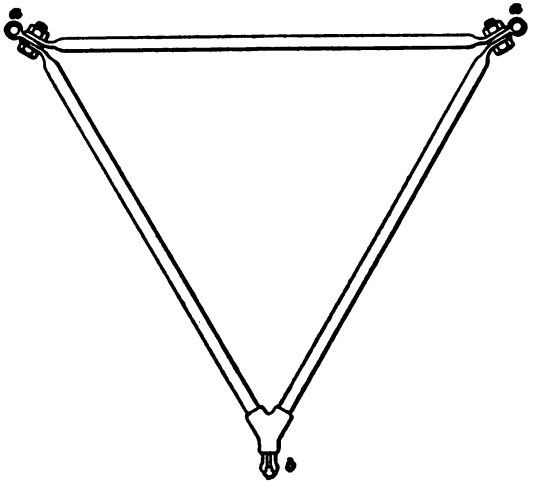

FIG. 63

hold the two messenger cables and clamp *b* holds the trolley wire.

RETURN CIRCUIT

56. Rail Return.—The track rails are used as a part of the return circuit in the electric-railway systems just described. The rails are carefully bonded together, so as to make the conductivity of the rail return as good as possible, and in some cases return feeders are connected to the rails and extend to the nearest main power station or substation. The earth also acts as part of the return circuit. Ground plates and cables at the stations or substations are provided to transmit the earth-return current to the generating apparatus.

57. Roadbed.—For heavy electric traction, the roadbed and track system is about the same as for steam roads. The standard track gauge of 4 feet $8\frac{1}{2}$ inches between the inside edges of the heads of the T rails is adopted.

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ELECTROLYSIS

58. Elementary Principles.—In Fig. 64 are shown two iron plates *A* and *B* buried a short distance apart in damp earth. If the terminals of these plates are connected to a dynamo and a current is made to flow from *A* to *B* through the earth, plate *A* will be eaten away or pitted, while plate *B* will not be damaged; this action is known as **electrolysis.** The point to notice is that wherever current flows from a metal conductor into the earth, the conductor is eaten away; but where current flows from the earth into the conductor, the latter is not damaged. One ampere flowing steadily for 1 year will eat away about 20 pounds of iron or 75 pounds of lead, so that the damage due to this effect may be a very serious matter.

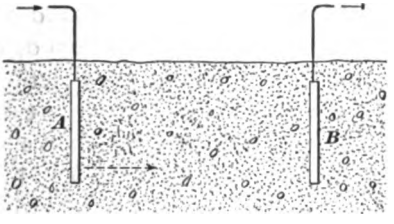

FIG. 64

59. Electrolysis Due to Railway Currents.—Fig. 65 illustrates the manner in which electrolysis may occur in

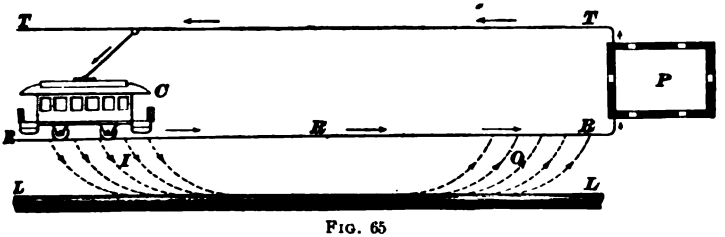

FIG. 65

connection with an overhead-trolley system. At *T* is shown the trolley wire and at *R* the track. Under ordinary conditions, the current is supposed to return to the power station *P* by way of the rail and earth, as indicated by the arrows.

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If, however, there happens to be a pipe *L L* near the track, and if this pipe offers a ready path for the current, part of the current will leave the rails, as at *I*, enter the pipe, and flow out again, as at *O*, to return to the power station. At *O*, where the current leaves the pipe, electrolytic action will be set up, and in the course of time it will eat holes in the pipe. At *I*, the current leaves the rails; hence, the rails at this place will be eaten away to some extent.

If the trolley wire were connected to the negative pole of the dynamo instead of to the positive, the current would flow out through the track and the pipe, and whatever corrosion occurred in the pipe would take place at points remote from the station and would be scattered over a wide area. On the other hand, with the positive pole connected to the trolley, any action that takes place on the pipe is confined to districts near the power house. These areas are comparatively small, and measures can be taken to protect them; as, for instance, by connecting the pipe near the station to the rails or to the negative terminal of the power station. This is the principal reason why the positive pole of the dynamo should be connected to the trolley side of the line; so far as the motors are concerned, they would operate equally well if the trolley wire were connected to the negative side and the rail to the positive side. If the resistance of the track return is made very low, there is not so much tendency for the current to leave the rails for parallel pipes. Electrolysis can, therefore, be greatly diminished by good bonding of the track rails.

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TYPES OF COLLECTORS FOR HEAVY TRACTION

TROLLEY SYSTEMS

INTRODUCTION

1. Having explained the general scheme of supplying current to the trolley wire and the third rail, the car devices that collect the current from the stationary conductors and transmit it to the apparatus on the moving car will now be considered. On ground-return systems, the current flows from the trolley wire or the third rail, as the case may be, through the car apparatus to the track rails. In order to transmit current from the stationary supply conductor to the moving car, sliding or rolling contacts called **current-collectors** are necessary; these are mounted on the car and bear against the stationary supply conductors. The number of current-collectors required per car depends on the nature of the supply system. On the single-wire, overhead-trolley system, one or two collectors are used, and on the third-rail system, four collectors, one at each corner of the car, are used. On many long-distance, third-rail systems, trolley-wire sections are installed at the terminal yards and, therefore, the cars are equipped with one or two trolley poles as well as with third-rail shoes.

2. On electric-railroad systems where current in some or all of the sections of the road is transmitted to the cars through a trolley wire, the current-collector takes the form

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of a grooved wheel, called the *trolley wheel*, pressed upwards against the wire by means of springs located in a supporting construction called the *trolley stand*. In Fig. 1, the devices composing an equipment are lettered in the order in which the current traverses them. The current path is, then, trolley wheel *a*–pole *b*–socket *c*–trolley stand *d*–terminal *e* –roof wire–hood switch or breaker *f*–roof wire–hood switch or breaker *g*–wall wire *h*–fuse box *i*–controller trolley wire *j*

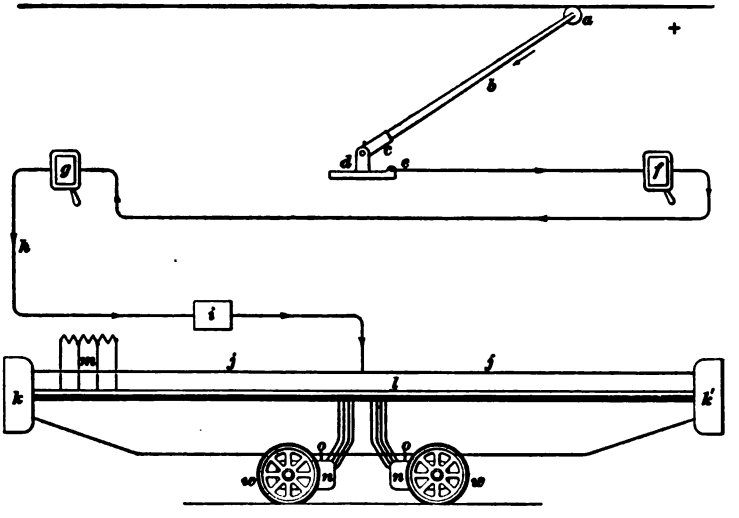

FIG. 1

–controller *k* or *k'* (according to which controller is used) –canvas hose *l*–resistance *m*–*l*–*k* or *k'*–*l*–motors *n*–*l*–*k* or *k'*–ground wire *o*, connected to motor frames–wheels *w*–rails.

THE TROLLEY

3. Parts of Trolley.—The collector complete, generally called the **trolley**, comprises five distinct parts: the *pole*, *ferrule*, *harp*, *contact springs*, and *wheel*.

4. Pole.—The **pole** is from 10 to 15 feet long. If the car must pass through a tunnel or a culvert or under a shed or a low elevated structure, the pole must be short and

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stout; if the car must cross steam-railroad tracks, where the wire is raised above regular height, the pole must be correspondingly long. A trolley pole is generally about $1\frac{1}{2}$ or $1\frac{5}{8}$ inches in diameter at the large end, and holds this diam-

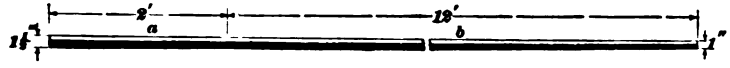

FIG. 2

eter for about 2 feet; then it tapers to a diameter of about 1 inch. Poles are hollow, to give them maximum strength for minimum weight. Most poles are made of steel and offer great resistance to bending; when bent, however, considerable force is required to straighten them. Fig. 2 shows the straight and the tapered part of a standard pole; part of the pole must be straight, to fit in the socket.

5. Ferrule.—Poles are often provided with a **ferrule** to receive one end of the trolley rope. This ferrule, as shown at *f*, Fig. 3, is a metal ring with an eye in it, and is secured to the small end of the pole. One end of the pole is shown at *p* and one end of the harp stem at *s*, while at *t t* is shown a pin passing into the pole and stem and through the ferrule. This pin fits the ferrule loosely, so that the latter can turn on it freely when the pole is swung around, but it is forced into the pole and harp stem and riveted by means of rivets *r*. A ferrule is not always used; its place is sometimes taken by an eye cast in a projection on the harp, as shown at *e*, Fig. 4. In either case, the hole should be well rounded, to avoid cutting the rope.

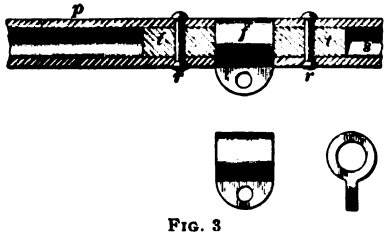

FIG. 3

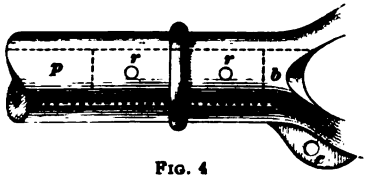

FIG. 4

Cutting of the rope at the pole is a source of much annoyance and delay and many schemes have been devised to

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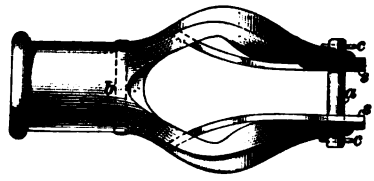
avoid it, but so far without satisfactory results. Fig. 4 shows the manner of attaching a harp directly to the pole. In this figure, the harp is shown at *b*, the small end of the pole at *p*, the rivets by means of which the two are fastened to the connecting pin, at *r*, and the eye provided to take the end of the trolley rope at *e*. Sometimes, the harp itself has a shouldered end that is driven into and riveted directly to the pole.



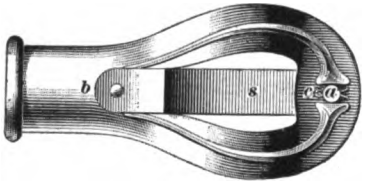


FIG. 5

6. Harp.—The **harp** is the fork that holds the wheel and the axle on which the wheel turns; it also holds the two contact springs *s*, Fig. 5. In this figure the harp proper is shown at *b*, the axle on which the wheel turns at *a*, the two flat springs on either side of the harp at *s*, and the two cotter pins that pass through holes drilled in opposite ends of the axle and serve to prevent end motion and rotation at *c*.

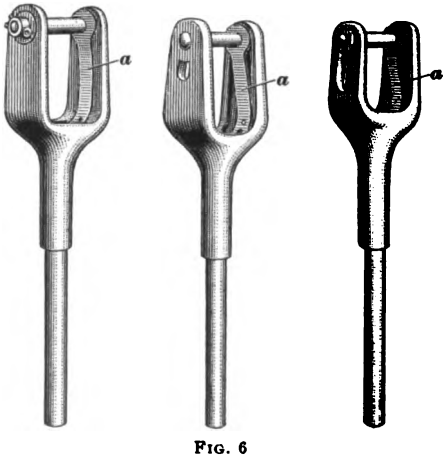


FIG. 6

It has been customary to make harps of brass; but brass is being replaced by malleable iron, which is cheaper, stronger, less tempting to thieves, and just as good for the purpose. *Brass* is a mixture of copper, tin, and zinc; *malleable iron* is cast iron that has been subjected to heat for several days and thus rendered much tougher and less

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brittle than ordinary cast iron. Malleable iron can be bent when cold, but cannot safely be hammered when hot; cast iron under any condition will often break if subjected to a blow.

The main points that govern the selection of a harp are narrowness, lightness, smoothness, and general shape. A harp should have no abrupt changes in shape; all edges should be rounded so as to avoid catching in the line work should the wheel leave the wire. Fig. 6 shows several styles of harps made by the General Electric Company; these harps have extensions that drive directly into the poles. A contact spring is shown at *a*; there being two of these for each harp. The selection of a good harp means a great saving in poles, ropes, harps, and line work.

7. Contact Springs.—The **contact springs** are pieces of spring copper that are riveted to the sides of the harp and have holes, as indicated in Fig. 7, through which the axle passes. The contact springs press against the sides of the wheel and serve two purposes: they lessen the end wear of the wheel and harp and conduct the current from the wheel to the harp. If the contact springs are omitted, all current taken by the car must pass through the bearing surface between the wheel and axle, and as soon as wear makes the fit at all loose, the bearing parts become blistered by the burning action of the current.

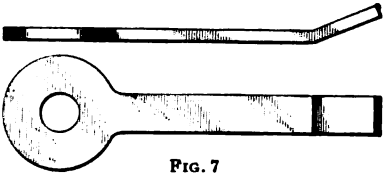

FIG. 7

8. Wheel.—Much experimenting has been done with the **trolley wheel** to determine the best shape of groove and the best composition of metal consistent with long life in both the wheel and the trolley wire. A wheel made of very soft metal will wear rapidly, while one made of hard metal or having a badly shaped groove will wear the trolley wire excessively at curves and turnouts. Many roads experiment to determine the groove and metal best adapted to local conditions. Some of the conclusions drawn from

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such experiments may be misleading, because the manner in which a wheel wears depends as much on the condition of the overhead work as on the wheel itself. Valuable lessons, however, can be learned from careful observation of wheel wear. Some wheels wear in one place and some in another; the same make and shape of wheel will wear differently on different branches of the same system; also, some cars wear out wheels faster than others.

Trolley wheels for ordinary service are usually about $4\frac{1}{4}$ inches in diameter over the flanges. Some wheels with an extra-deep groove have a diameter of $4\frac{1}{2}$ inches. For high-speed work on interurban roads, the wheels are made

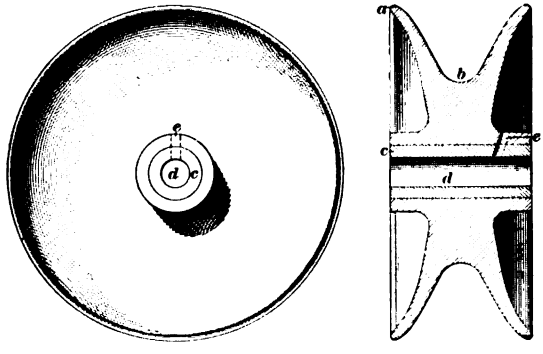

FIG. 8

as large as 5 or $5\frac{3}{4}$ inches in diameter, so as to reduce the speed of rotation of the wheel and the wear on the bushing and axle. If both flanges of a wheel persist in wearing to a knife edge long before the bearing surface is worn out, the groove is too deep or too narrow, or both, for the trolley wire. If the groove persists in wearing to one side, it indicates that the wheel flanges do not run parallel with the trolley wire or that the trolley wire is not central.

Fig. 8 shows a type of trolley wheel in general use, the flange being shown at *a*, the groove at *b*, the bushing or bearing at *c*, the hole through which the axle passes at *d*, and the oil hole at *e*. The bushing is a very important part; it first gives evidence of wear because wear in it causes the

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wheel to rattle. A bushing should be well made and carefully looked after; whether self-lubricating or not, it should

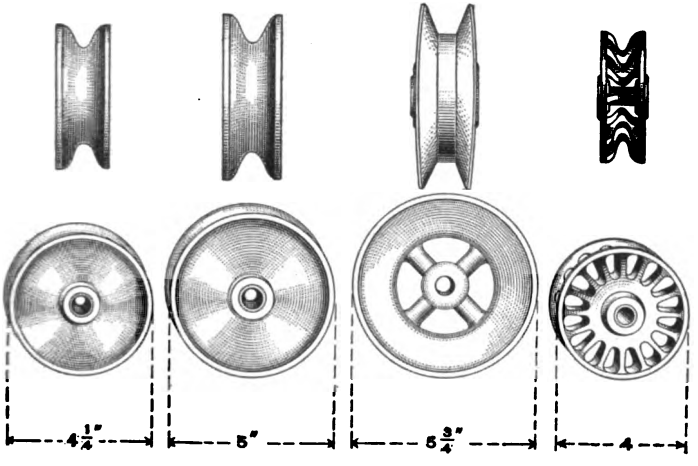

FIG. 9

be inspected at intervals and oiled when necessary. To keep an ordinary bushing in good running order, it should be oiled every 15 or 20 miles, for when it is taken into consideration that the wheel makes about 5,000 revolutions for each mile the car runs, and that the car speed is usually several miles an hour, the importance of a good bearing is not difficult to realize. Fig. 9 shows several styles of trolley wheels.

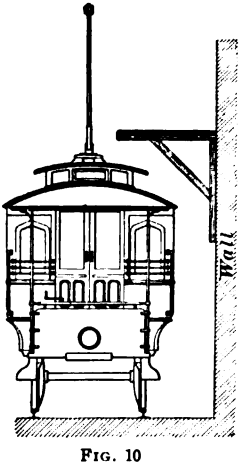

FIG. 10

9. On roads that look after the trolley wheels, a platform, Fig. 10, is built that overhangs the car roof, so that the wheel can be inspected and, if necessary, oiled whenever the car passes that point. When a trolley wheel is allowed to run dry, the hole in the bushing wears oblong, allowing the wheel to vibrate and omit a disagreeable, chattering noise. Many wheel troubles, however, are not due to any defect in

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the wheel itself. Some men put new wheels on an old axle, without noticing the wear in the axle itself. All trolley axles in use should be kept up to gauge, and all axles and wheels issued from the storeroom should be gauged to see that they are of standard diameter. A chattering noise may also be caused by flat spots in the wheel groove. These flat spots may be due to the wheel sliding along, for want of oil, instead of turning, or to sliding at intervals on account of one flange binding on the harp. In such a case, the harp will show abrasion. In other cases, the flat spots may be due to imperfections in the wheel itself; for example, the metal may have soft spots in it. In any case, the wheel should not be run after it begins to chatter, but should be taken out, and, if there is stock enough left to warrant it, rebushed and turned down in a lathe.

TROLLEY STANDS

10. The trolley pole is held by a device called the **trolley stand**, which gives the pole the vertical motion that enables it to adjust itself to stretches of wire varying in height above the ground, and also allows the pole a sidewise motion, so that it can follow changes in the direction of the trolley wire and can be swung around when the direction of the car is changed. The trolley stand has two members: the upper member, which carries the pole socket, is called the **trolley base**, or **spring base**, and the lower member, which is secured to the top of the car through the board, or bridge, is called the **trolley foot**. The base, which includes the socket, the tension spring, and the devices for adjusting the tension spring, turns on the foot as a center in a plane parallel to the top of the car. The foot is screwed or bolted to a board on top of the car and has a terminal to take the wire leading to the car circuits.

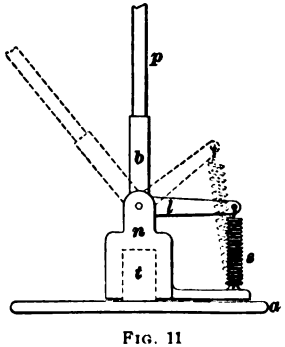

FIG. 11

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11. Simple Trolley Stand.—In Fig. 11, a trolley foot is shown at *a*. The upper part of this foot takes the form of a pin, or pivot, *t* over which fits the lower part of the base *n*. At *b* is shown the socket, and at *s* a spring by means of which the wheel, at the end of the pole *p*, is pressed up against the wire. In the position indicated by the full lines, the pole stands vertically; spring *s* is relaxed, and therefore exerts no influence on the socket casting. When, however, the pole is pulled over to the running position, as indicated by the dotted lines, the arm *l* on the socket casting rises and stretches spring *s*, whose tension keeps the wheel pressed against the trolley wire. This figure is merely symbolical and is given to show the relations of the several parts.

12. Socket.—Fig. 12 shows the construction of a socket and its manner of gripping the pole. In this figure, the pole is shown at *p* and the socket at *n*, while at *b* are

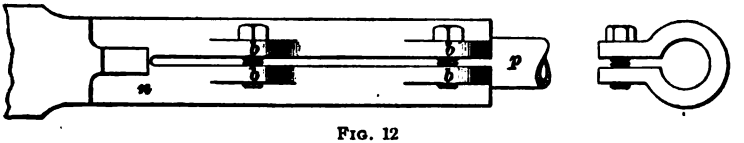

FIG. 12

shown lugs cast on the socket to receive setscrews. The space between the jaws and the lugs allows the socket to take poles whose bases vary in diameter. When the base of the pole is so small that the jaws draw together without clamping it, a lining must be used; a piece of tin or sheet iron will answer the purpose. The base of the pole must be straight for part of its length; if it were tapering, the socket could not grip it tightly. If it is necessary to use a lining to make the socket grip the pole, no material should be used that will prevent the current from flowing from the pole to the socket; also, if there is much japan, or paint, on the end of the pole, it should be scraped off before the pole is placed in the socket.

13. Bridge.—The trolley bridge is a board or an arrangement of stout slats, more or less springy, supported

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at the ends on cross-pieces, as shown in Fig. 13. The bridge serves three purposes: it provides a means of securing the trolley foot without boring holes in the car roof; it

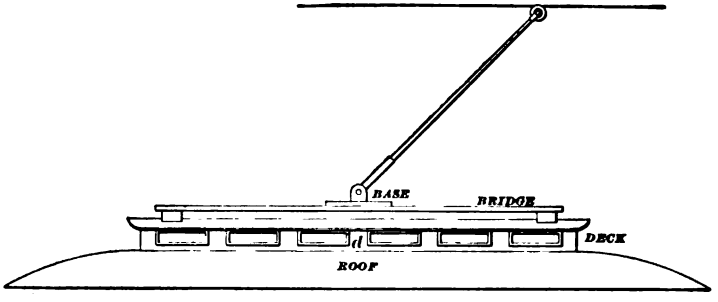

FIG. 13

saves the roof in case the trolley stand is subjected to heavy stresses due to the pole being caught in the line work while the car is under headway, for if the trolley stand is torn from its seating, only the bridge is injured; and it acts as a spring to minimize the effect that the jolting of the car might have on the wheel. The *deck* is the raised part of the car roof, as indicated at *d*. The ventilating windows, or ventilators, are commonly called *deck sashes*.

The trolley foot is fastened to the bridge with either bolts or lagscrews. *Lagscrews* are large tapered screws with a coarse thread and are screwed into holes bored very little smaller than the screws. They have the advantage that they will pull out and allow the stand to be torn off, in case of a sudden wrench, without tearing off the bridge or part of the car roof. Bolts, on the other hand, are more secure, and provide a means of connecting the car wiring to the trolley stand, as indicated in Fig. 14, in case no other connecting device is provided. If the end of the car wire has no terminal, the wire is bent into an eye, placed over the bolt between two washers *c*, and the nut screwed down.

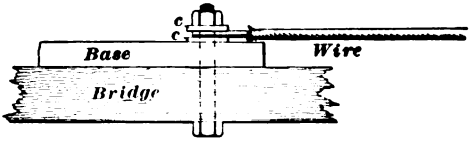

FIG. 14

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14. U.S.-13 Trolley Stand.—There are many styles of trolley stands in service. In Fig. 15 is shown the **U.S.-13 trolley stand** made by the General Electric Company and designed for high-speed interurban service. The socket *a* is pivoted at *b* and has an arm *c* to which four springs are connected. The other ends of these springs are connected to an arm *d*, which is part of a slide *e*. The slide is mounted on a projection *f* of the trolley base, and the tension of the springs may be adjusted by the adjusting screw *g* at the end of the slide. The tension springs force the trolley wheel against the wire. The trolley base may be swung around on the trolley foot to suit either direction of car movement, a

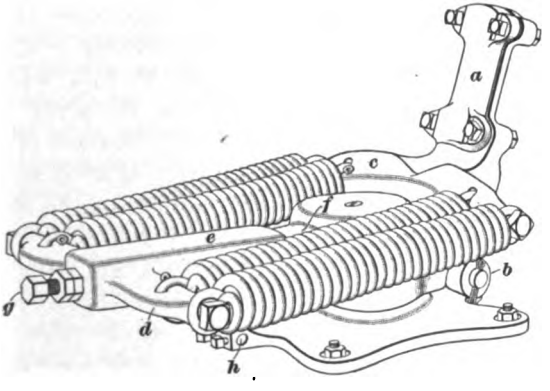

FIG. 15

roller bearing between the base and the foot being provided for this purpose. The car roof wire is connected to the trolley foot at *h*.

TROLLEY TROUBLES AND THEIR REMEDIES

15. Causes.—**Trolley troubles** may be due to faults in the trolley devices themselves or to faults in the overhead line construction. If all cars on a given road or division have trolley troubles while those on other divisions do not, it is reasonable to conclude that the fault is in the line of that particular division. If only a few of the cars give

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trouble with their trolleys, it is probable that the trolleys are defective, and they should therefore be carefully examined.

16. General Precautions.—The pressure of the wheel against the wire varies from 20 to 40 pounds, according to local conditions, such as smoothness of roadbed, speed of cars, and relative shape of groove and trolley wire. The compression or tension on the trolley spring is greater than the upward pressure of the wheel on the wire, because the wheel is much farther from the turning point, or fulcrum of the socket, than is the spring. The compression required on the spring depends on the pressure desired on the wire, the weight and length of the pole, and the weight of the harp and wheel. If the compression is so adjusted that a certain wheel presses against the wire with a force of 25 pounds, and a heavier wheel or harp, or a longer, heavier pole, is substituted, the pressure of the wheel against the wire will be less. If the upward pressure of the wheel is too weak, the wheel will be unable to respond promptly to local changes in the direction of the overhead wire, and will jump off at every slight kink or twist; if the pressure is too strong, it causes abnormal wear in the wire, bushing, and axle, and considerable difficulty is experienced in replacing a wheel that has jumped off the wire.

17. A car should never be run with the pole turned the wrong way, because, if in the shed, the pole might be bent and rendered useless for the time being by coming off and hitting some of the car-barn timbers; or if on the road, the harp is liable to catch in an overhead frog or hanger and pull down the line. On many roads, there is a severe penalty attached to the offense of running a car with the pole turned the wrong way, even when there is a conductor or a trolley boy watching it. If the pole comes off while the car is in motion, it should be pulled down at once and the motorman given the emergency signal to stop. The pole should not be replaced until the car has stopped, because there is danger

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of striking a span wire or a frog and doing damage to the pole, stand, car roof, or line. Such an accident as the pole being jerked out of the socket and striking the driver of a passing team has happened.

18. The wheel is most likely to leave the wire at curves, crossings, and temporary cross-overs, and there are several defects that increase this tendency. The pivot around which the base turns on the foot may need greasing, in which case the base refuses to turn promptly, even after the car has taken a switch for a distance of several feet; the wheel tries to follow the main line wire while the car is on the branch rail and is thus forced off the wire. There are a number of other causes for a wheel leaving the wire: the trolley pole may be skewed in the socket; the harp may not be straight on the pole; or the harp itself may be twisted as the result of some previous accident. In any of these cases, the result of rounding a curve is to turn the flange of the wheel against the wire; and if the latter has the slightest kink in it or the flange is at all rough, the wheel will jump off.

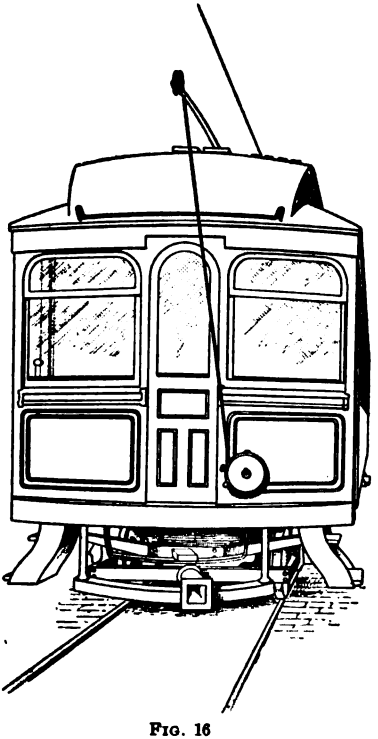

FIG. 16

TROLLEY RETRIEVERS

19. With the advent of high-speed cars, devices were introduced for catching the trolley pole when the wheel leaves the wire, thus preventing the pole from flying upwards and damaging the overhead work. Some of these trolley

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catchers merely catch and hold the trolley pole when the wheel has risen a few inches above the wire. Other devices, known as **trolley retrievers,** catch the trolley rope as it flies upwards with the pole and draw it down until the wheel is 3 or 4 feet below the trolley wire. The device is attached to the dash iron of a car, and can be easily transferred to the other end of the car when the pole is turned.

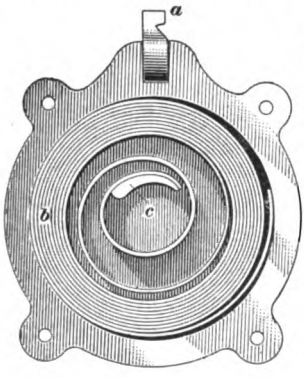

FIG. 17

20. Description.—In Fig. 16, a *Knutson trolley retriever, No. 2,* is shown in position on the dash iron of a car. After the retriever has operated, the trolley pole is in the position shown in the figure and is in no danger of interfering with the overhead wires.

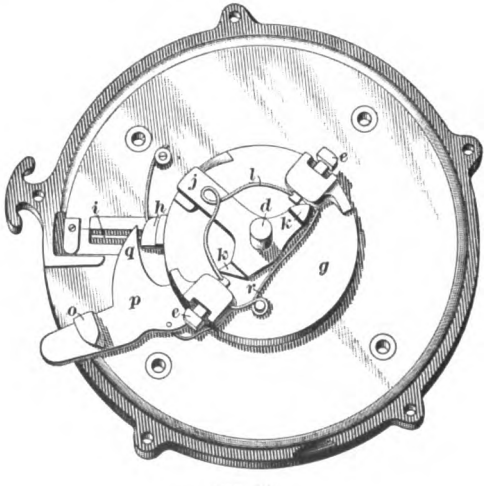

FIG. 18

The part of the case next to the dash iron is shown in Fig. 17, it being fastened in place by a simple locking device *a*. The powerful retrieving spring *b* is located in this

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portion of the case. At the end of the spring is provided a catch *c* that engages with the inside end of the shaft *d*, Fig. 18. The actuating disk is shown in Fig. 18. The disk and outer cover are secured to the inner case by screws passing through the lugs on the edges of the cover, disk, and case. The actuating disk bears the releasing mechanism, which throws the retrieving spring into action. In Fig. 19 is shown the reel on which the trolley rope is wound. The reel is inverted and placed on shaft *d*, Fig. 18, so that its face is next to the face of the actuating disk. This reel contains a comparatively weak spring, shown in the interior of the reel case, Fig. 19, the object of which is to take up the slack in the trolley rope.

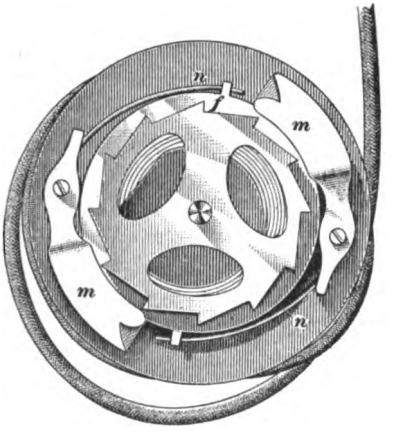

FIG. 19

21. Operation.—The spring in the reel keeps the trolley rope taut while allowing the trolley pole to move up and down as the height of the wire above the ground varies. When the wheel jumps off the wire, the retrieving spring is thrown into action and the trolley pole pulled down.

When the retriever is in released position, dogs *e*, Fig. 18, are in their extended positions and engage in the teeth of ratchet *f*, Fig. 19, on the reel. To reset the device, the rope is pulled out from the reel by hand. This revolves the reel on shaft *d*, Fig. 18, in a clockwise direction, when looking at the cover on the complete device. It must be kept in mind that the reel is inverted from the position shown in Fig. 19 when placed on shaft *d*, Fig. 18. The inside end of the reel spring is fastened indirectly to the cover, and the outside end of the spring to the reel. Revolving the reel in a clockwise direction winds up the reel spring, and as the dogs *e*, Fig. 18,

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engage the ratchet *f*, Fig. 19, the disk *g* and shaft *d*, Fig. 18, are also revolved. The inner end of the shaft *d* engages with the catch *c* at the end of the retriever spring *b*, Fig. 17. The spring *b* is thus being wound up as the reel and shaft turn in a clockwise direction. As disk *g*, Fig. 18, mounted on the actuating disk, revolves, a cam located below *g* moves the locking key *h* out from under the disk on the stationary slide way *i*. When *h* has moved out to the position indicated in Fig. 18, after a few revolutions of the reel, the key *h* locks the spring *b*, Fig. 17, and holds *d* from turning. Arm *j*, Fig. 18, is rigidly connected to shaft *d*. Disk *g* is indirectly connected to shaft *d*, and there is a space for a small movement of *j* on disk *g*. The tension of *b*, Fig. 17, after key *h*, Fig. 18, has locked, forces the arm *j* to take a position at the right side of its small throw space on the disk; this causes the beveled surfaces *k* of arm *j* to disengage the inner ends of dogs *e*. Spring *l* then forces inwards dogs *e*, and thus mechanically disconnects disk *g*, Fig. 18, and ratchet *f*, Fig. 19. The reel now revolves on shaft *d*, Fig. 18, and is independent of the retrieving mechanism. The reel spring also is wound up by the operation, and after the trolley wheel is put on the wire, the reel spring acts to keep the rope taut. The tension of the reel spring is adjusted by means of a spanner placed in holes in a small ring in the center of the outside case. A screw just above the ring prevents the adjusting ring from turning when adjustment has been made.

The device is now in operating condition. If the trolley wheel leaves the wire, the rope is suddenly pulled out of the reel, which causes a violent jerk on the reel case. This sudden jerk tends to revolve the reel at a high rate of speed. The rope pulls out only a few inches, however, before the heavy dogs *m*, Fig. 19, are thrown outwards by centrifugal force. These dogs are kept in their normal positions by springs *n*, and are not affected by the ordinary turning movements of the reel. A sudden movement, however, causes the dogs *m* to fly out, and when in their extended positions one of them strikes against lug *o* on arm *p*, Fig. 18. The arm *p* is mounted on the actuating disk and has a small

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throw in a clockwise direction from its present position. The arm *p* is forced toward key *h*, and extension *q* presses against the top of *h*, forcing *h* in toward the center of the actuating disk. The action of key *h* is now to unlock spring *b*, Fig. 17, and the disk *g*, Fig. 18. As soon as *h* unlocks, arm *j* and disk *g* revolve together, the tension of *b*, Fig. 17, on *j*, Fig. 18, is relieved, and spring *r* pressing on extension *k* forces *j* to the left end of its throw. The beveled extensions *k* now force the dogs *e* outwards and they engage with ratchet *f* on the reel. This locks the reel to the disk *g*, and the spring *b*, Fig. 17, in unwinding turns the reel in a counter-clockwise direction, when looking at the cover of the completed device, and thus winds up the trolley rope and pulls down the pole to a safe position. The end of arm *p*, Fig. 18, extends outside of the cover, and the tripping mechanism may be sprung by hand when desired.

REPLACING THE TROLLEY

22. Trouble at Frogs.—Suppose that a car approaches a frog in the overhead line work similar to the one shown in Fig. 20 in the direction indicated by the arrow. The main line wire on the approach end of the frog is at *c*, its continu-

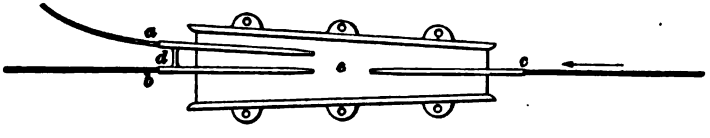

FIG. 20

ation on the other end at *b*, and the turnout that follows the curve at *a*. At *d* is shown a support for the two ridges at the left end of the frog. A certain place *e* in the frog has no wire nor ridge to guide the wheel, and the wheel is supposed to be guided past this gap by the frog flanges. When a frog is in good order and the track switch is turned so as to keep the car on the main line, the wheel will follow the main line wire without any trouble, because there is nothing to lead it elsewhere; but if the frog is tilted downwards a little on the

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main line *b* side, the wheel is apt to slide over to the high side and take the turnout wire, although the car itself keeps to the main line. If the frog is crooked, so that the wires *c* and *b* are not parts of the same straight line, a rough edge on the wheel or the frog flange will cause the wheel to ride the frog and go off. A kink in the wire close to the frog will also throw off the wheel.

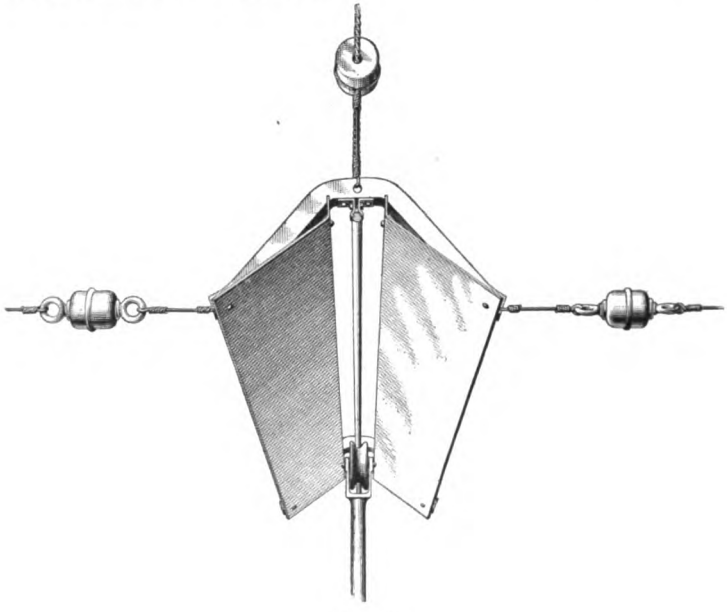

FIG. 21

Suppose that the car is intended to take the turnout; the trolley wheel trails after the car, and the car will therefore have changed its course before the trolley wheel. When the car enters an open switch, it moves some distance around the curve before the trolley wheel reaches the line frog; then, when the wheel does reach the frog, the side pull on the pole throws the wheel over to the proper side and the frog flange guides it to the turnout wire.

23. Trolley Guards at Crossings.—A trolley wheel is likely to leave the wire at crossings. This is especially

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the case at steam-railroad crossings, unless the car is run over them slowly, because at such crossings the wire is strung high enough to avoid the smokestacks of locomotives, as well as the heads of brakemen on freight trains. The height of the wire requires the trolley pole to stand almost vertically, in which position there is little pressure between the wheel and the wire.

In Fig. 21 is shown one type of **trolley guard.** Guards of this type are installed at railroad crossings, under bridges, at curves, or wherever it is dangerous to have the trolley wheel lose contact with the wire. In case the wheel flies off the wire, the guard will lead it back into proper position on the wire. The guard is held in position by special suspension wires.

24. Trolley Replacer. — Many devices have been invented that will assist in the act of replacing the trolley

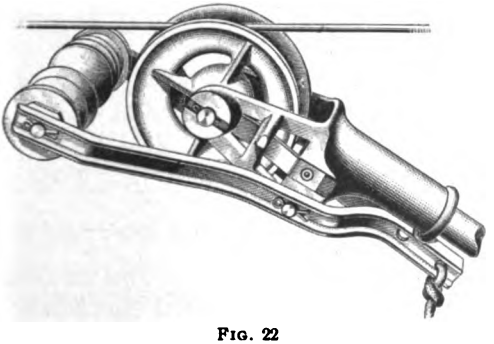

FIG. 22

wheel on the wire. In Fig. 22 is shown one type of **replacer** in normal position while in Fig. 23 is shown the same replacer in action. When in normal position, the idler, which is mounted on the end of a fork pivoted to the harp, is 1 or 2 inches below the trolley wire. If the trolley wheel leaves the wire, the idler will, under usual conditions, catch the wire. The idler has deep spiral grooves that extend in reverse direction toward the center. When the trolley rope, which is attached to the idler fork, is pulled, the idler is raised above the trolley wheel, as shown in

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Fig. 23, and the grooves on the idler return the wheel to the center position below the wire, the car still being in motion, since current can flow through the idler. If the

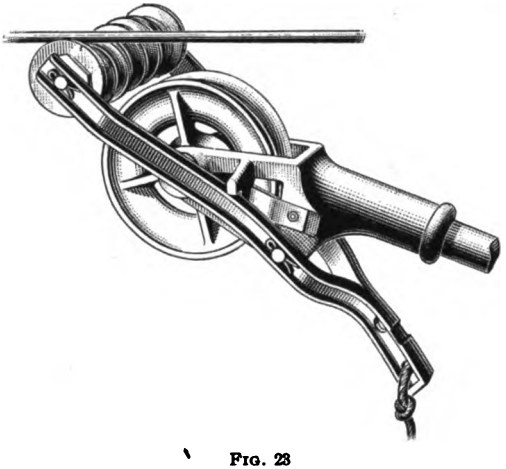

FIG. 23

trolley rope is then released, the idler drops to its lowest position, leaving the trolley wheel on the wire.

CARE OF TROLLEY

25. When a crew looks after its own car, the following points may be profitably observed: The wheel should be mounted so as to run true in the harp; the harp should be true and straight on the pole; and the pole should be free from bends, and should be so set in the socket that when the wheel is on the wire the latter rests on the bottom of the groove and lies parallel to the wheel flanges. This adjustment should be made on a stretch of straight track where the trolley wire is known to be centered. A crew should understand the manner of adjusting the compression or tension of the springs of every stand with which it has to do; a careful inspection will generally indicate the peculiarities of a stand and its method of adjustment.

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26. Greasing.—All moving parts of a trolley should be kept clean and greased. The pivot on the foot around which the base turns should be oiled or greased whenever it causes sluggish action while swinging the trolley. A dry pivot makes it difficult to replace the wheel on the wire, and the excessive wear that follows will cause binding, which will prevent the base from turning freely when swinging the pole. The axle around which the socket casting turns should be oiled or greased once a week or oftener; the trolley wheel should be oiled whenever its axle runs dry. All collars, spindles, or sheaths used to guide the tension or compression springs should be greased whenever sluggish action shows that they need it; these guides should not be allowed to become sticky with an accumulation of old grease and

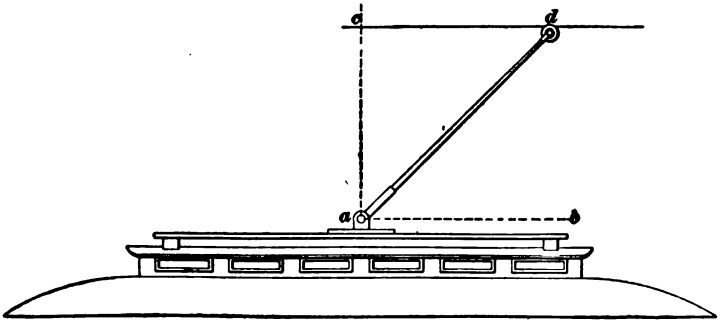

FIG. 24

dust, as such a condition is much worse than no grease. When a car comes in for overhauling, it is interesting to test the trolley-wheel pressure on the wire before and after the parts are given a thorough cleaning and oiling; the difference in many cases is surprising.

The trolley pole should always be swung by means of the trolley rope whether the car is on the road or in the shop; also, the man that swings the pole should be on the ground. It is dangerous practice for a man on the top of a car to attempt to swing a pole by hand.

27. Length of Pole.—In Fig. 24, the line *a b* is parallel to the car roof. The trolley wire is shown at *c d* and the

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pole at *a d*. When the pole is of the proper length, it should, under average conditions, make an angle of 45° with the trolley wire; that is, the angle *a d c* should be 45°. Under average conditions for high-speed service, with the trolley pole making this angle with the trolley wire, the pressure against the wire should be about 25 pounds. The practice in this respect, however, varies widely on different roads. Whatever may be the wheel pressure adopted, every road should provide means for testing the stands to find out whether the pressure is correct.

28. Adjustment of Spring Compression.—One simple method of adjusting the spring compression is to fix a trolley foot permanently to the shop floor; then, as cars come in, their bases are removed and slipped on to the foot before and after overhauling, and the compression of the springs tested with an ordinary spring balance, as indicated in Fig. 25, where *p* shows the pole and *a b* the trolley wire. In order that poles of different lengths may be adjusted to standard pressure on the wire under the same conditions, a stop, or gauge, *c* should be used to show when the pole is inclined at an angle of 45°. When the pole is at this angle with the floor line, the rope or wire connected to the spring balance should be hooked over the trolley wheel and the vertical pull of the pole measured. A vertical pull of 25 pounds, or whatever the standard pressure between wheel and wire may be, should barely cause the pole to leave the stop that limits its upward movement.

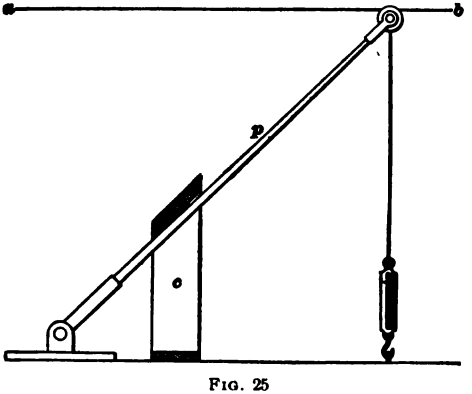

FIG. 25

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THIRD-RAIL SYSTEM

ARRANGEMENTS OF COLLECTING SHOES

29. **Third-rail systems** are ground-return systems, because the track rails are part of the working circuit. After the current has passed through the car circuits, it returns through the track rail to the power station. Instead of the positive conductor being in the form of an overhead wire, it consists of a heavy steel rail running alongside the track rails, but insulated from them.

The current-collector takes the form of a shoe called the **contact, or third-rail, shoe;** it is suspended and insulated from the side of the truck.

30. **Usual Arrangement of Collectors.**—Fig. 26 shows a common arrangement of the collecting shoes on a third-rail car. In this figure, the third rail is shown at *a a*, while at *b* is shown one of the insulators on which the third rail rests. The shoe proper is shown at *c* and is suspended from the shoe frame by means of links; at *d* is shown the wooden shoe beam attached to the side of the car truck. A terminal piece on the shoe frame has a cable *e* and the flexible copper tap *f*, called the **shoe shunt,** attached to it. A fuse *g* is sometimes installed to cut off the current in case of short circuits; this is called the **shoe fuse.** Cable *e* connects to the other contact shoes and to the car apparatus.

31. The third rail is not always located on the same side of the track; hence, every car must have shoes on both sides. Also, since the continuity of the third rail is broken at switches, crossings, etc., shoes are installed at the front and back ends of the car, in order that the car will never be without a shoe on the third rail. Every car operated on a third-rail system has four shoes: two shoes on each end, on

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opposite sides of the same truck. At places where the continuity of the rail is broken, a forward shoe engages the

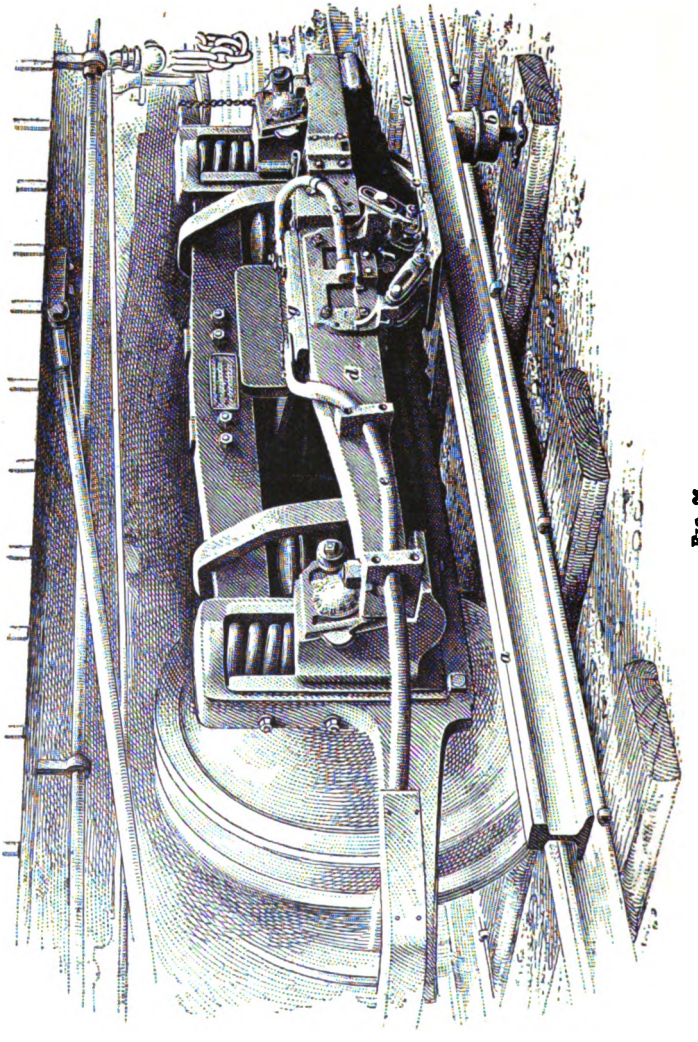

FIG. 26

approaching section of rail before the rear shoe leaves the receding section, and where the third rail changes from one side of the track to the other, the shoe on one side engages

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the rail on that side before the shoe on the other side leaves the rail.

32. All shoes on a car are connected together, as indicated in Fig. 27, where the shoes are shown at *c* and the shoe shunts at *f*. If one of the shoes bears on the third rail, all the other shoes on the car are alive. Cable *e* leads to the car circuits. As a current-collector, the shoe is free from the tension troubles of overhead trolleys. The weight of the shoe is sufficient to insure good contact, and since the shoe is wider than the rail, it is able to cover local lateral changes. As the rail is stiff and substantially supported, these local changes can occur only at joints, and if all rails composing the third rail are of the same cross-sectional dimensions, a little attention will prevent joint troubles.

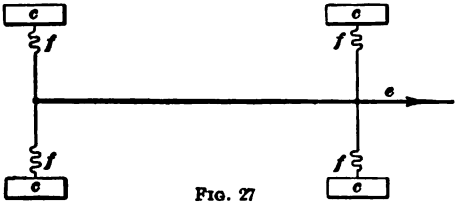

FIG. 27

33. Ordinarily, third-rail shoes cannot leave the rail; but they are sometimes torn or burned off. If a shoe catches in a joint or on a bolt head in the wooden guard-rail that is sometimes run alongside of the track rail, it is liable to be torn off. If a shoe for any reason drags an arc after it when it leaves a section of rail, the arc is liable to burn off the cotter pins that secure the link pins, and if these pins work out, the shoe will drop off. On a third-rail system, the live wires leading from the third rail are very close to the grounded parts, such as track rails, truck parts, etc., and if any of these wires come in contact with the grounded parts in any way, a short circuit follows. Care must be taken when installing shoes that none of the shoe-frame bolts come too near metal truck parts, or touch bolts that touch any metal part of the truck. There is considerable length of wire between the shoe and the first device to use the current; if any part of this wire becomes grounded, a short circuit follows, and the only thing that can stop the flashing,

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in case there are no shoe fuses, is for the short circuit to burn itself out or for a power station or substation safety device to operate. To minimize the damage done when such a short circuit occurs, shoe fuses are installed as near the shoes as practicable. The current used by a car is seldom collected by more than two shoes, because, ordinarily, the third rail is located on either one side or the other and not on both sides of the track. All current collected by any shoe must pass through its shoe fuse. A ground anywhere on the negative side of the shoe fuse will cause it to blow and open the circuit.

34. The shoe shunt *f*, Fig. 26, is provided for the same reason that the contact springs are provided on the trolley

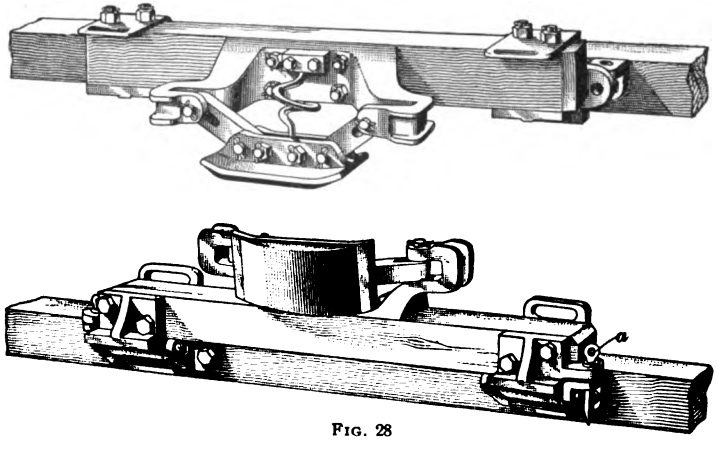

FIG. 28

wheel, namely, to prevent the current from passing through the supporting links and blistering them. At present, third-rail construction is employed only where heavy motor cars or trains constitute the service. This necessarily means that heavy currents must be collected, and these, if allowed to pass through the links and their connections, would make their bearing surfaces rough. Where the shoe shunt is used, the greater part of the current takes the path through the shunt instead of through the links. Shoe fuses are not used on all roads; where used they should be protected, so that

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when they blow there may be no demonstration. The blowing of a shoe fuse is not serious in itself, but at night it makes a display that is liable to create a panic among passengers on the cars or on station platforms.

Fig. 28 shows a neat type of contact shoe and rigging in which no shoe fuse is shown, but which admits of one being easily installed. The shoe beam can be turned up when not in service, thereby raising the shoe from the third rail. The beam is secured in its upper position by a pin *a*. This is a very convenient feature where the service is partly overhead and partly third rail, as all contact shoes can be lifted from the rail and kept out of the way when the car is operating on the overhead system. A shoe fuse can be installed in conjunction with any type of contact shoe.

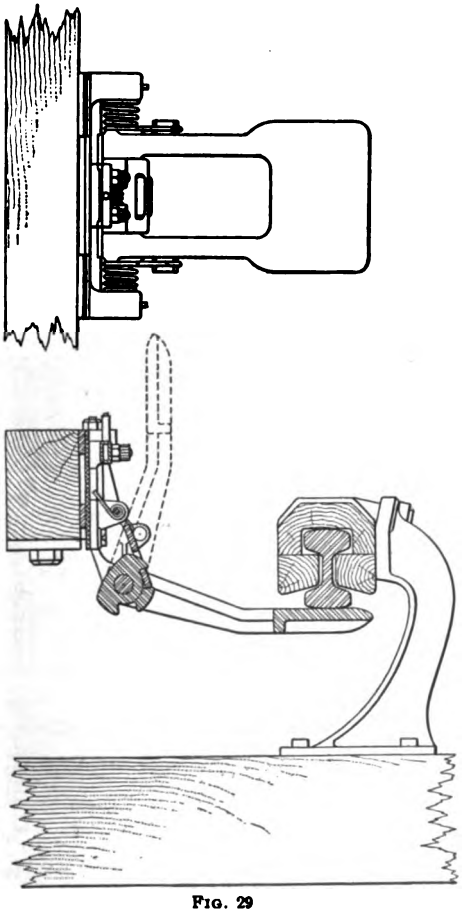

FIG. 29

35. Under-Running Collectors.—An **under-running, third-rail shoe** is used on the New York Central and Hudson River Railroad and on the West Shore Railroad. A shoe of the type applied to motor cars is shown in

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Fig. 29. The shoe springs force the shoe up against the under surface of the third rail. When the shoe is not in service, it can be raised and locked in the position indicated by the dotted outline.

36. Tunnel Third-Rail Collectors.—In Fig. 30 is shown the type of third-rail construction used in the Hudson

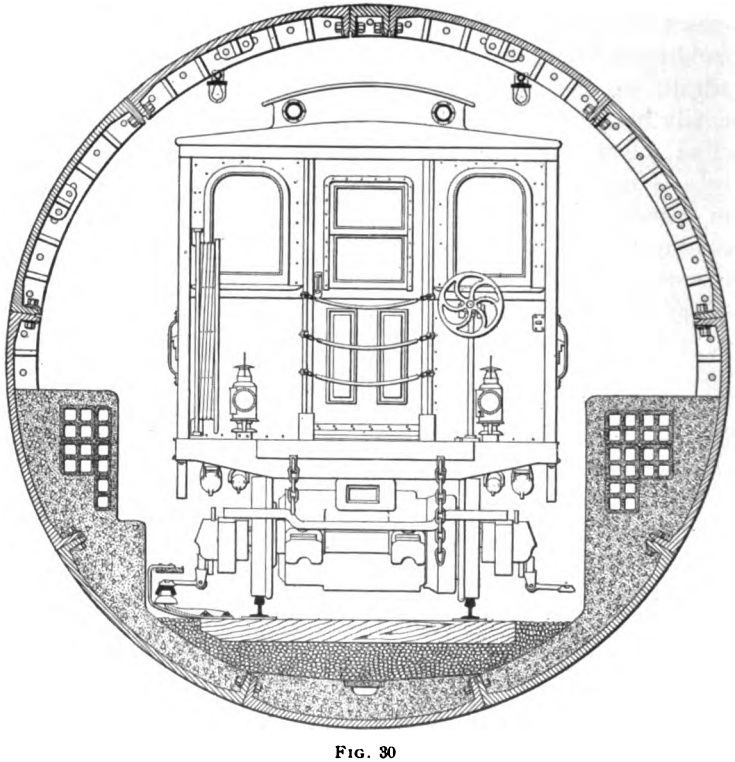

FIG. 30

River tunnels of the Hudson and Manhattan Railway Company and in the East River Tunnel of the Interborough Rapid Transit Company. The third rail is of the inverted V section, and is mounted on insulators that are supported on iron brackets. The brackets are fastened to the ties by screw spikes. Where the clearance will not permit of this construction, the insulators are mounted on a pedestal

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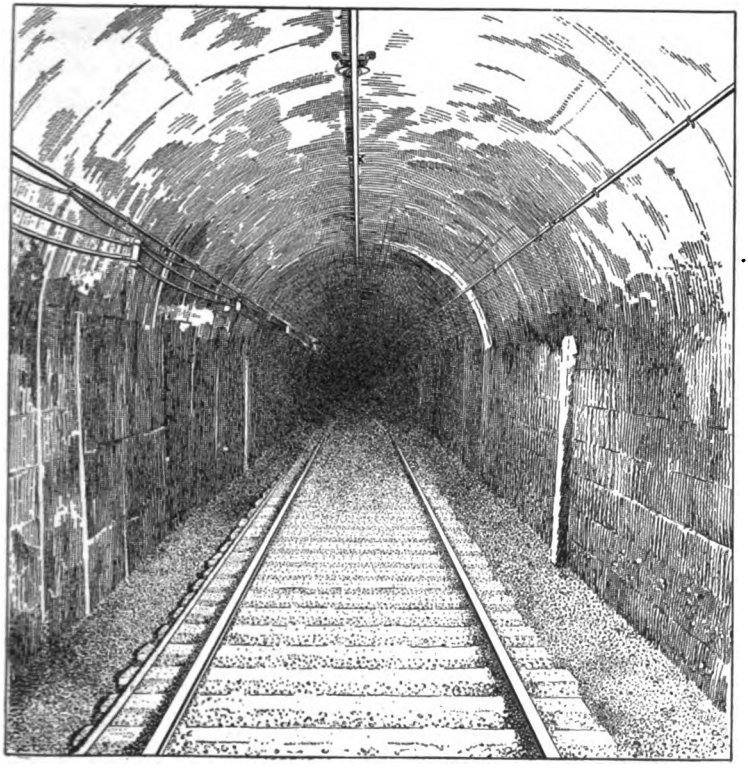

FIG. 31

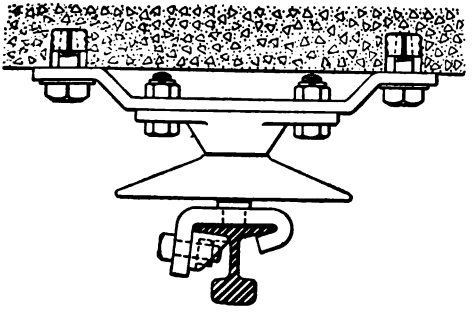

FIG. 32

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embedded in the concrete walls of the tunnel. A protection board is installed above the third rail. The ducts at each side of the tunnel are provided for the feeder cables. These cables are tapped to the third rail at intervals.

37. In the East River Tunnel of the New York and Long Island Railroad Company, the third rail is mounted at the top of the tunnel, as shown in Fig. 31. The method

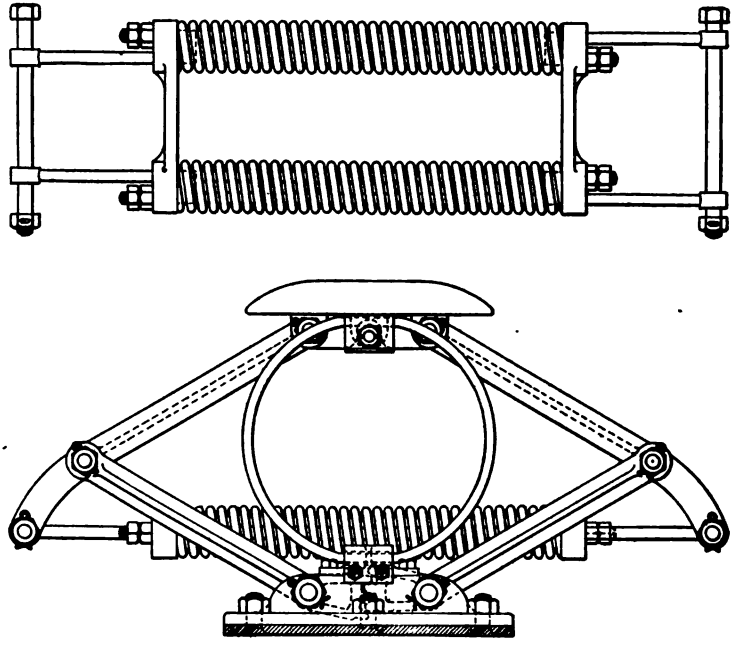

FIG. 33

of mounting the third rail in the concrete section of the tunnel is shown in greater detail in Fig. 32.

In Fig. 33 is shown the type of current-collector used with the overhead third rail. It is mounted on the roof of the car, and the shoe is forced up against the inverted third rail by the shoe springs. This collector is similar to the type used on the electric locomotives of the New York Central and Hudson River Railroad Company where short sections of overhead third rail are installed at the New York Terminal.

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THIRD-RAIL DANGERS

38. On account of an overhead wire being, as a rule, so far removed from all parts that are grounded, workmen seldom get a shock as the result of direct contact with the wire and the ground. In third-rail construction, however, the third rail and the ground are everywhere very close to each other, and it is an easy matter, with the unprotected type of construction, to touch both at the same time.

39. Trolley and Ground Parts.—The contact rail, shoe, shoe fuse, and shoe frame are all **trolley parts,** and are connected to the positive side of the circuit. All parts of the trucks and, as a rule, all iron parts of the car, such as brace rods, gates, chains, rails, couplers, and bumpers, are **ground parts,** or are connected to the negative side of the circuit. Any one touching a trolley part and a ground part at the same time is sure to get a shock. Workmen learn to identify the grounded parts of a car, and they know enough not to touch a grounded part and a trolley part simultaneously; but there are special cases in which the grounded part is not easy to identify. On a wet day, it is possible to get a shock by standing on the car structure and touching any connection leading to the third rail. On a dry day, a shock can be obtained by standing on a bolt or a nail head that is in connection with the trucks and touching any connection leading to the third rail. If any contact shoe on the car rests on the contact rail, all shoes on the car will be alive, because all are metallically connected. Accordingly, workmen should never undertake to make repairs on any trolley part of the car without first seeing that all shoes are lifted.

40. Special Precautions.—In order to lift the shoe that is arranged as shown in Fig. 28, it is simply necessary to raise the beam; the beam is then secured with a pin. Where shoe riggings of the type shown in Fig. 26 are used, it is customary to carry on each car two paddle-shaped pieces of wood called *slippers*, by means of which the shoes can be raised. The slippers are inserted between the shoes and the

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rail. The workman, however, must bear in mind that, although all shoes may be raised, the third rail is still alive. Accordingly, before trying to make extensive repairs on a truck or a shoe rigging over the live rail, the workman should take the further precaution of covering that part of the rail with a dry board, a dry wooden trough, or a piece of sheet rubber. Many men have been hurt through disobeying orders and trying to replace shoes, shoe fuses, shoe pins, shoe shunts, or to pack a journal-box over a live rail without taking the prescribed precautions.

41. Third-Rail Guards.—Some roads protect the contact rail with two wooden boards, called **third-rail guards**, arranged on either side of the contact rail. Unless the third rail is very completely protected, as is the case in some of the more recent installations, it is doubtful whether this precaution is a wise one. Experience shows that the men learn to place too much confidence in the protecting power of the rail guard, with the result that they become too bold in exposing themselves.

42. Snow and Ice on Third Rail.—Snow on a third rail gives very little trouble except when the third rail has wooden guards on both sides and thus permits the snow to lodge and pack in a manner to interfere with the operation of the shoes. There is, however, one condition under which operation is rendered difficult; this occurs when the temperature falls below the freezing point while it is raining, turning the rain into sleet and forming a thin, hard ice skin on the contact rail. This film of ice will not conduct current, and it is exceedingly difficult to remove; hence, most of the efforts to deal with it are directed toward preventing its formation. Among these methods may be mentioned the following: Swabbing the surface of the rail with oil; running hot brine on the rail from a tank carried on a special car; providing a stiff brush or a scraper in front of the contact shoe; and covering the surface of the contact rail with an overhanging guard. The method named last is the most

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effective, but at present the majority of third-rail roads do not use a conductor rail with a protection of this kind.

43. Fig. 34 shows an arrangement for protecting the third rail. The primary object of this arrangement is to prevent persons from coming in contact with the live rail, but the cover, or guard, *c* also protects the rail from snow and sleet. The conductor rail *a* is of rectangular cross-section, so as to be easily manufactured, and is supported on insulators *b*. The guard is made of channel irons *c* and is sup-

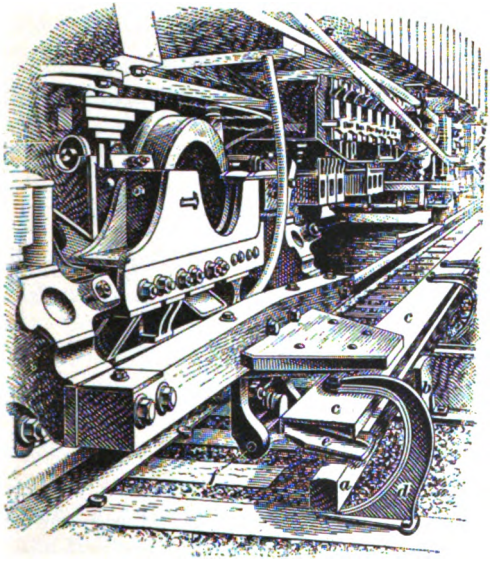

FIG. 34

ported by brackets *d*. If a less expensive guard is required, boards may be substituted for the channel irons. The construction of the collecting shoe is also shown, the shoe *e* being arranged so as to project under the guard. The shoe is hinged at *f* and is held in contact with the third rail by a spring.

If ice accumulates on the third rail, it is practically impossible to operate the cars, because the ice is exceedingly difficult to scrape off. Therefore, when the scraper method is

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used, the cars must be equipped with a sufficient number of scrapers, and these must be put into action promptly enough to prevent the formation of an ice skin.

44. Fig. 35 shows a form of scraper used on the New York elevated roads. This scraper consists of a number of steel plates *a* cast into a block *b*, the plates being set on a slant so that they will bear end-on on the rail, but with the plates lying diagonally across the rail, so that they will glide over the rail joints without catching. The scraper is pressed down by the flat spring *c*, and the casting in which it slides

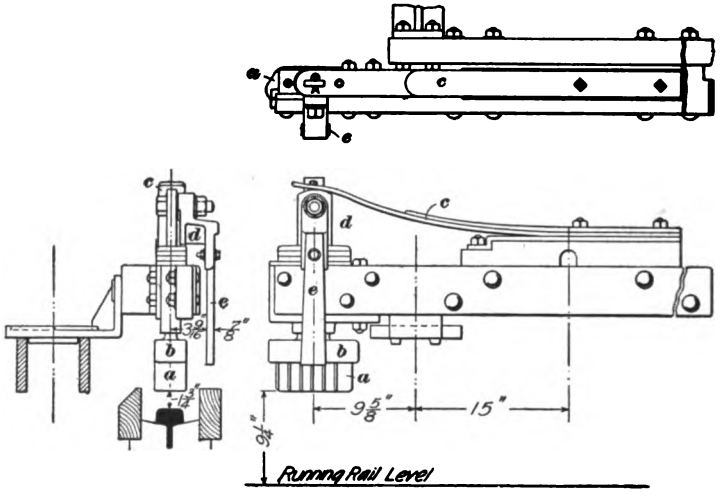

FIG. 35

is supported by the same beam, attached to the truck, that carries the current-collecting shoe. A cam *d* is provided to hold the scraper off the rail when it is not needed. The scrapers can be raised or lowered by the motorman, or they can be operated automatically by a tripping device alongside the rail and controlled from a central office, the cam being moved by means of the arm *e*. One of these scrapers is placed near each contact shoe on each car, and as the trains are run at short intervals, the formation of ice on the third rail will be prevented under ordinary conditions.

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COLLECTORS FOR CATENARY CONSTRUCTION

45. In high-speed railway work, it is essential that the current-collecting device should always remain in contact with the trolley wire while the car is in action. If the current-collector should leave the trolley wire while the car is moving at a high speed, great damage to the overhead work would probably ensue. The liability of such an accident occurring has been reduced by improved systems of overhead line construction and new forms of current-collecting devices.

PANTAGRAPH TROLLEY

46. Description.—A type of **pantagraph trolley** is shown in Fig. 36. The trolley is secured to the top of the car by the feet *a*, which are insulated from the other parts of the trolley by the massive insulators *b*. The main operating cylinder is shown at *c*, and a latch cylinder at *d*. A hook *e* on the lower side of a contact shoe *f* engages with the latch when the trolley is in its lowered position, as indicated in Fig. 37. The steel contact shoe is broad, so as to have a large surface in contact with the wire, and it is customary to stagger the trolley wire slightly so that the wear on the conducting surface of the shoe will be distributed. Grease is used on the shoe to reduce the wear on the wire. The shoe is so long that it cannot leave the wire under normal conditions.

47. Operation.—The pantagraph is operated by means of compressed air. Pipes connect to the main cylinder and to the latch cylinder. The pantagraph is normally held in a raised position against the wire by compression springs *k*, Fig. 38 (*a*). These springs force piston rods *l* and pistons *m* toward the center of the main cylinder, thus causing short

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levers *g* and shaft *i*, Figs. 36 and 38 (*a*), to rotate in a counter-clockwise direction, when viewed from the left side

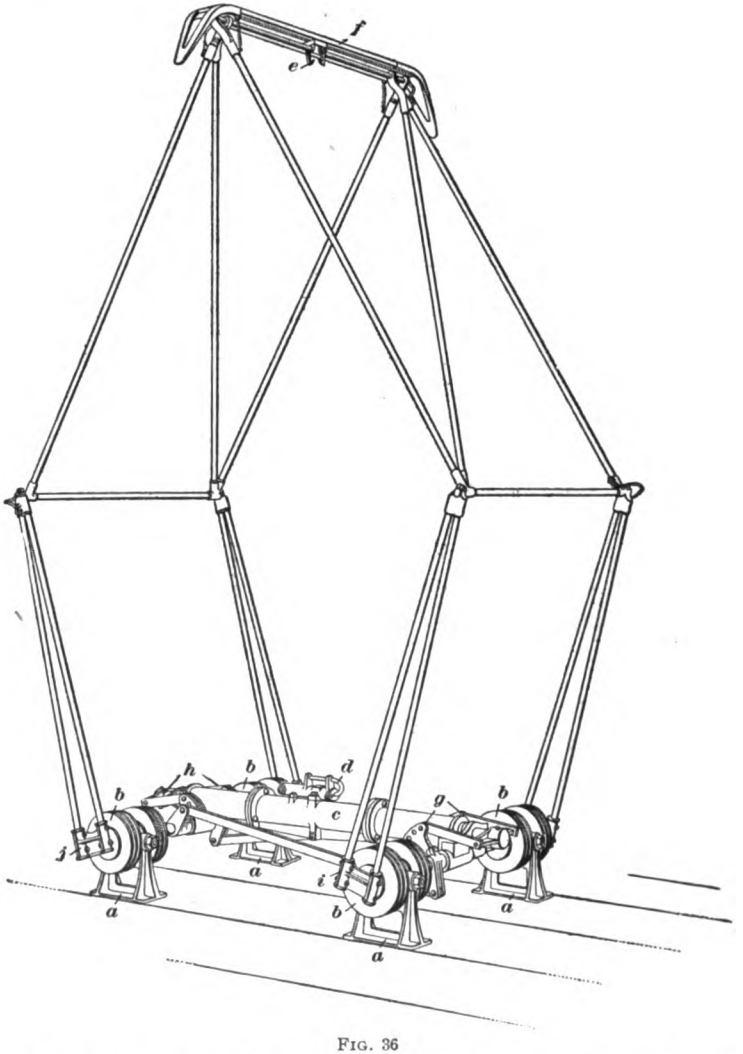

FIG. 36

of Fig. 36 and the front of Fig. 38 (*a*), and levers *h* and shaft *j* to rotate in a clockwise direction. The arms attached

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to the shafts are forced upwards, and the shoe is pressed against the trolley wire.

In order to lower the trolley, compressed air is allowed to flow into the center of the main cylinder. The pistons *m*,

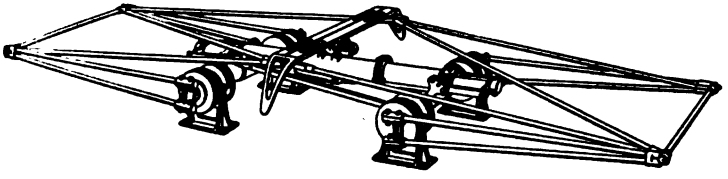

FIG. 37

Fig. 38 (*a*), are forced outwards, shaft *i*, Figs. 36 and 38 (*a*), rotated in a clockwise direction, shaft *j* rotated in a counter-clockwise direction, and the trolley lowered to the position shown in Fig. 37.

When in this position, the hook *e*, Fig. 36, which is divided into two parts, automatically catches around a projection from latch-cylinder piston *n*, Fig. 38 (*b*), which forms latch *o*, now in its closed position. A spring in the latch cylinder normally keeps piston *n* in such a position that the latch *o*

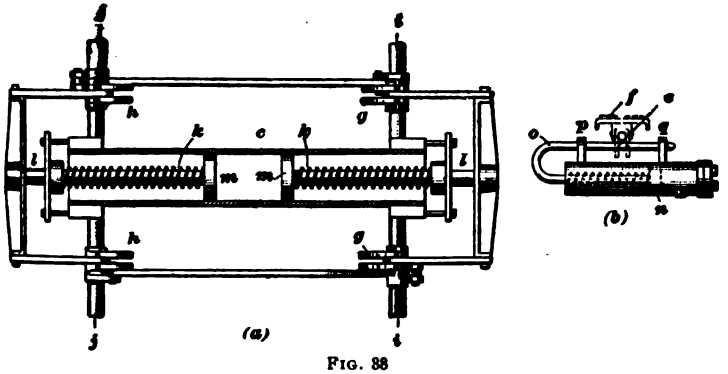

FIG. 38

extends through lugs *p* and *q* on the cylinder, and when the trolley is down, through hook *e* on the contact shoe *f*. The compressed air is then turned off from the main cylinder, and the latch holds the trolley down.

When it is desired to raise the trolley, air is momentarily admitted into the latch cylinder; this moves piston *n* and

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latch *o* so as to release hook *e*. The main cylinder springs then raise the trolley. The air in the main cylinder between pistons *m*, Fig. 38 (*a*), acts as a buffer as the pistons are forced toward each other, thus preventing too sudden action

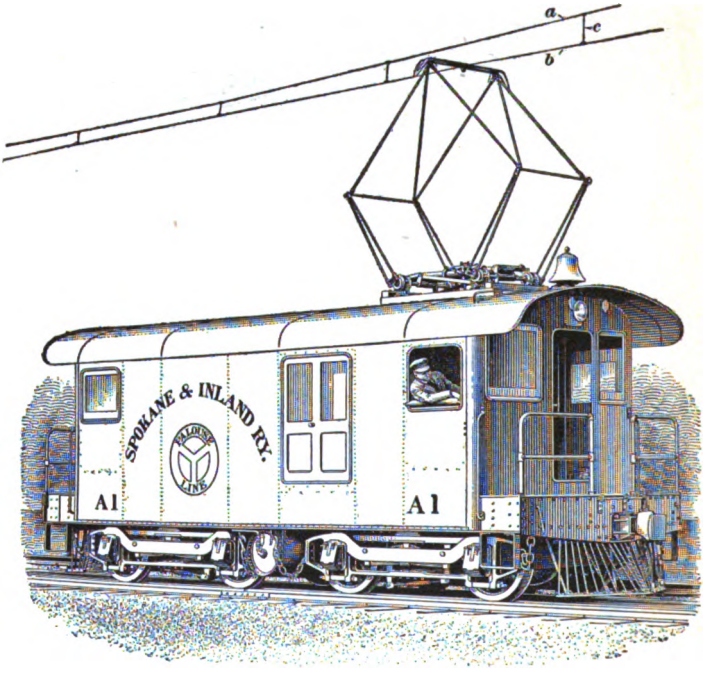

FIG. 39

of the springs. In Fig. 39 is shown an electric locomotive provided with a pantagraph trolley. The messenger cable is shown at *a*, the trolley wire at *b*, and the hangers at *c*.

BOW TROLLEY

48. The **bow type of trolley** is shown in Fig. 40. This trolley is raised and lowered by compressed air, under the control of the motorman. The upper bow portion *a* of the trolley assumes a nearly vertical position and has freedom of movement independent of the two main trolley

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poles. The movement is controlled by the springs *b* and *c*. The pair of springs *b* keeps the sliding contact shoe against the trolley wire when the car is moving in one direction, and the other pair of springs *c* serves the same purpose when the car is moving in the opposite direction. The main portion of the trolley remains in the same position for either direction of car movement. The bow portion,

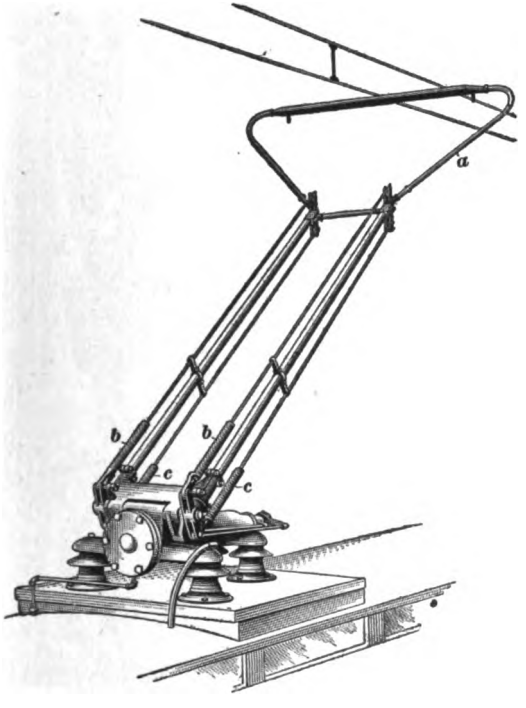

FIG. 40

however, inclines slightly in a direction opposite to the direction in which the car moves. An electric car equipped with a bow trolley is shown in Fig. 41. This car is also equipped with two direct-current trolleys, one or the other of which is used when the car is passing through the city streets. The bow trolley is used for the high-speed interurban service.

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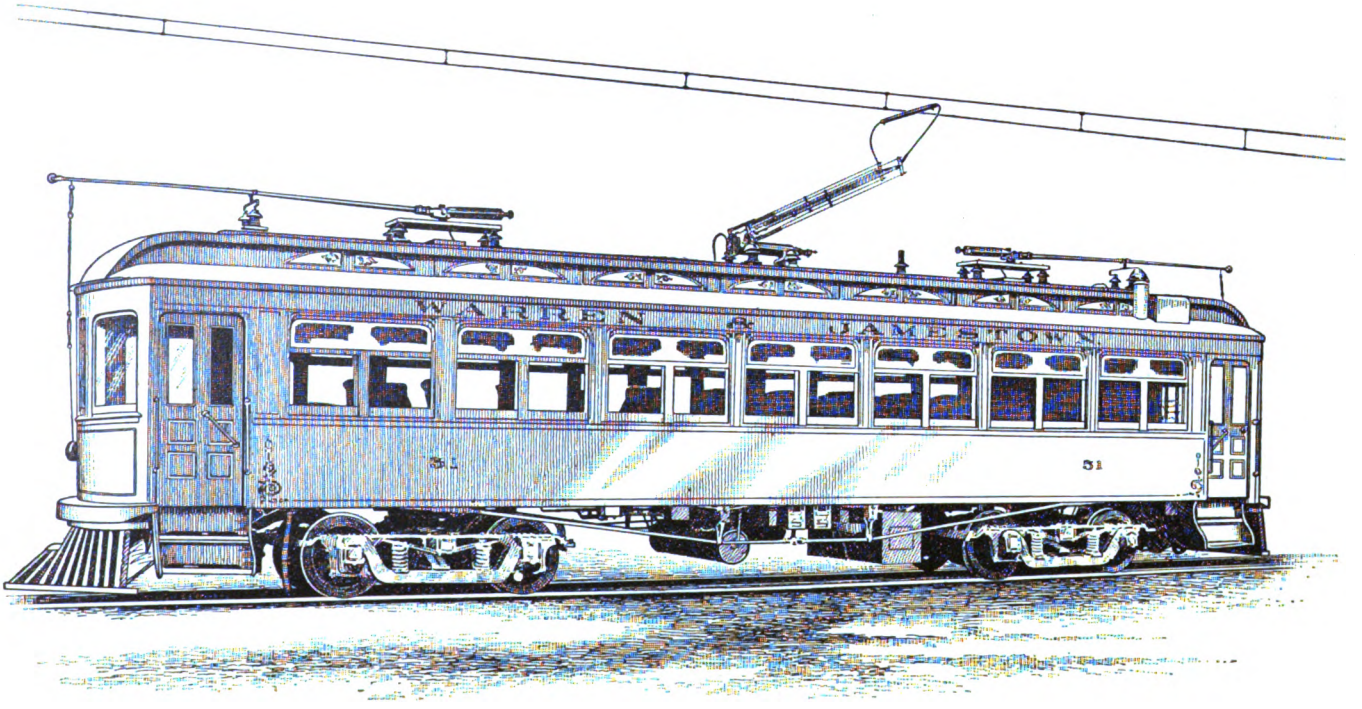

FIG. 41

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AUXILIARY DEVICES

SWITCHES

49. The devices used on multiple-unit electric cars to open a circuit are *switches*, *fuses*, and *circuit-breakers*. The switch is thrown by hand, but the fuse and circuit-breaker operate automatically to open the circuit when an excessive current is flowing. Circuit-breakers may also be operated directly by hand or through a trip magnet actuated by a remote control switch.

50. Main Switches.—In Fig. 42 is shown a type of **main switch** sometimes installed in the motor circuit of multiple-unit cars and often located on the switch panel in the motorman's cab. It is connected in circuit near the main tap leading from the trolley or third rail. This switch is designed to carry a large current, but it is not intended to open the motor circuit while current is flowing, unless, in case of an emergency, the circuit-breaker fails to operate. When the switch is opened, the upper blade leaves the switch jaws and puts in tension the two springs connecting the upper and lower blades. When the tension becomes sufficiently strong, the lower blade leaves the switch jaws very suddenly and opens the circuit. The speed of opening the circuit is such that the arc that starts to form, if current is flowing, is quickly disrupted. The main switch is used normally to cut off the apparatus on the car from

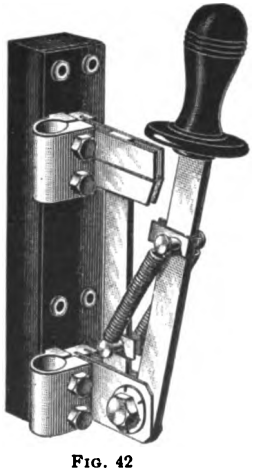

FIG. 42

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connection with the trolley or the third rail, in case the apparatus is to be inspected or the car is to be out of service.

51. In Fig. 43 is shown another style of switch that is sometimes used as a main switch for equipments of a capacity not exceeding 200 horsepower. This switch is often called a **hood, or canopy, switch.** A magnetic blow-out coil is connected between the right-hand switch terminal and the block to which the switch arm is connected, as indicated by the dotted lines. The magnet is located in the lower portion of the switch box. The magnet poles set up a strong magnetic field near the switch contacts.

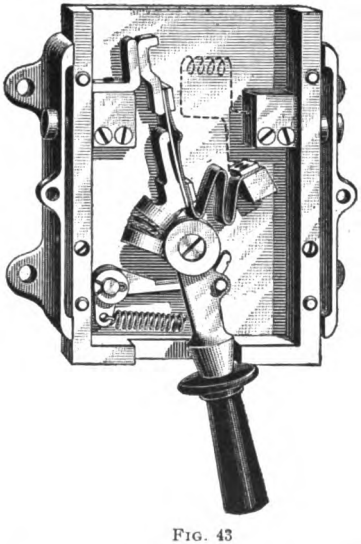

FIG. 43

When an arc is formed between two terminals on opening the switch while current is flowing, the conducting vapor acts like a flexible wire carrying current. A wire carrying current will, when placed in a magnetic field, tend to move across the field, on account of the interaction between the lines of force due to the current in the wire and the lines of force of the magnetic field. This action is explained in *Direct-Current Dynamos.* The arc placed in the magnetic field cannot move bodily across the field, because the positions of its ends are fixed by the positions of two sides of the gap across which it is maintained. The result is that the magnetic reaction stretches the arc until it becomes so long that the voltage is unable to maintain it. This action, if the arc is formed in a strong magnetic field, takes place so quickly that the arc is instantly blown out. The direction in which the arc is blown depends on the polarity of the pole pieces and the direction of flow of

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current in the arc. This method of suppressing arcs is used in a number of pieces of apparatus, such as controllers, fuse boxes, switches, lightning arresters, etc.

52. Disconnecting Switches.—Disconnecting switches are sometimes installed in the car wiring. A type of **double-blade disconnecting switch** suitable for high-tension work is shown in Fig. 44. The live portions of the switch are mounted on the top of insulators. The switch is opened by means of a wooden stick having in its end a hook that may be inserted in the hole in the switch blades. These switches are not intended to be opened when current is flowing, their purpose being to disconnect part of the apparatus from the live circuit in case of disorder, or if an inspection is necessary, without interfering with the operation of the rest of the apparatus.

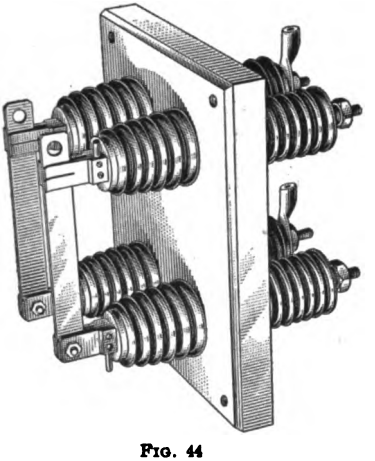

FIG. 44

53. Oil Switches.—Where high-tension circuits carrying currents may have to be opened, **oil switches** are often employed. The switch fingers and contact arm are immersed in insulating oil. When the switch is opened, the insulating oil rushes into the spaces between the fingers and the contact arm and thus prevents the formation of an arc.

In Fig. 45 is shown a type of oil switch used on multiple-unit cars equipped for operation on the single-phase alternating-current system. The operating magnet is shown at *a*. When the magnet is energized from the control circuit, the armature *b* is drawn up and the bell-crank *c* is rotated in a clockwise direction. The lever *d* that lifts the contact arm is pivoted at *e*. A link, shown by the dotted lines, connects the upper end of the bell-crank and a point *f* on the lever *d*.

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When the bell-crank moves in a clockwise direction, the link raises lever *d*, and this in turn raises the contact arm *g* into connection with the contact fingers *h*. Lever *d* is connected to arm *g* by means of a crosshead *i* and a hickory rod *j*.

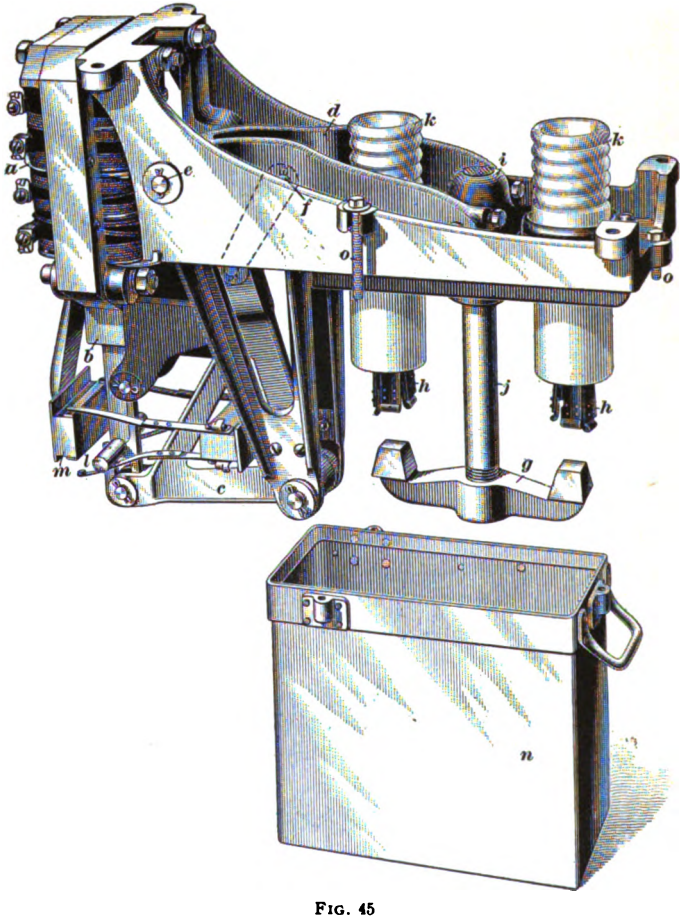

FIG. 45

The porcelain insulators *k* are provided for the high-tension wires—one wire from the trolley and the other wire leading to the car transformer.

When in its lower position, a pin *l* on the armature *b* depresses two contact springs, and when pin *l* is in its upper

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position, it raises two contact springs. One or the other of these pairs of springs makes contact with contact piece *m*. The springs and contact piece constitute what is known as *interlock switches*. The purpose of these switches is to make the closing or opening of certain control circuits dependent on the position of the main switch. Interlock switches will be explained more fully in connection with the study of multiple-unit car-wiring systems.

The vessel *n* contains the insulating oil, in which the live-switch parts are immersed, and when in position, is attached to the frame by capscrews, two of which are shown at *o*, *o*. If the current through the operating coil ceases, the switch opens by gravity.

FUSES

54. Enclosed Fuses.—A **fuse** consists of a metal conductor, and it is connected in series with the circuit that it protects. Some fuses are made of an easily fusible alloy of different metals and other fuses are made of copper wire or strip. The current-carrying capacity of the fuse installed in a circuit is such that the fuse will melt and thus open the circuit in case a current flows that is dangerous for the wires or for devices connected in the circuit.

Formerly, fuses were exposed to the air, but a more modern type is the **enclosed fuse**, one of which is shown in the right-hand side of the master-controller switch box, Fig. 46. The fuse wire, or strip, is enclosed in a hollow cylinder made of tough insulating material. The fuse metal occupies the hollow space, and it is surrounded by a finely divided powder, such as plaster of Paris mixed with powdered borax. This powder, when

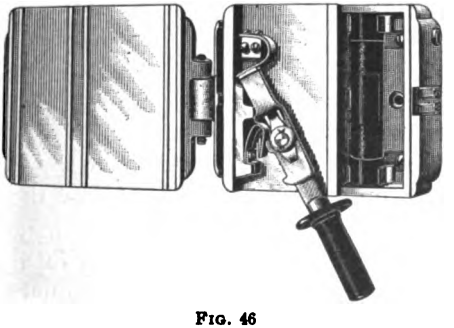

FIG. 46

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the fuse melts, fluxes with the molten metal, rendering it non-conducting and thus suppresses the arc. Terminal rings are provided at the ends of the cylinder, and these fit into switch clips on the fuse block. An indicator is provided on the fuse in order to show whether or not the fuse is blown. This indicator is usually in the form of a small paper disk placed near the center of the cylinder and becomes discolored when the fuse is burned.

55. Magnetic Blow-Out Fuses.—A type of **magnetic blow-out fuse box** is shown in Fig. 47. The fuse consists of a copper ribbon stretched between terminal blocks. The cross-section of the fuse is decreased at the center by a hole punched in the fuse. The central portion of the fuse thus has the least current-carrying capacity, and the fuse will melt at that point. The arc takes place some distance from either terminal, and the terminals are less liable to damage than if the fuse melted at a point near one of them.

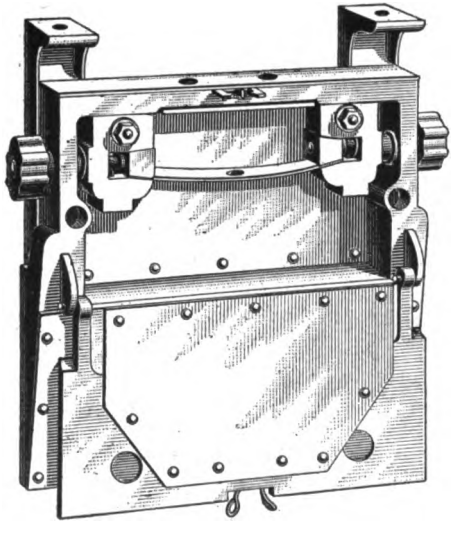

FIG. 47

The blow-out coil is connected between one fuse terminal and one of the box terminals; and the action of the coil is to extinguish the arc almost as soon as it is formed. After removing the ends of the blown fuse, a new fuse is installed by placing the ends of the copper strip in the terminal clamps and then turning the knobs that draw the tapered plugs into the clamps, thus making a firm contact between the fuse and the terminals.

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56. Expulsion Fuses.—For high-tension car circuits, an **expulsion fuse**, one of which is shown in Fig. 48, is sometimes used. The fuse is inserted in a tube made of insulating material. Terminal pieces on the tube fit into switch clips mounted on porcelain insulators. When a fuse blows, the sudden accumulation of gas in the chamber at the base of the fuse expels the metal vapor and blows out the arc. The tube may be removed from the clips and a new fuse wire inserted.

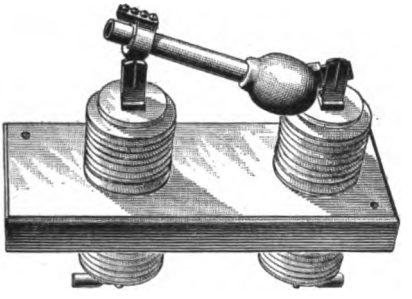

FIG. 48

CIRCUIT-BREAKERS

57. Circuit-breakers are installed on a car to open the motor circuit automatically in case an excessive current flows. In Fig. 49 is shown a type of circuit-breaker used on cars requiring 200 amperes or less to drive them. The operating coil of this circuit-breaker also acts as a blow-out magnet and disrupts the arc, which is formed when the breaker opens under load, blowing the hot gases out of the flue shown at the left. The breaker is closed by means of the handle, and it may be opened by pressing on the tripping button shown near the top of the breaker.

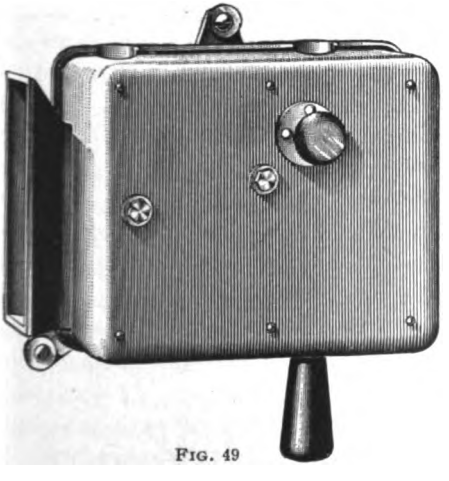

FIG. 49

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58. In Fig. 50, the breaker is shown with the cover removed. The breaker terminals are shown at *h* and *i*. The switch arm *e* projects into the blow-out flue. A small compression spring *s*, which is located between the top portion of the handle and the switch arm, insures good contact between the switch surfaces in the blow-out flue when the breaker is closed. The main contact brush is made up of strips separated by small spaces. With a brush of this kind, a good contact can be secured, even if the contact surfaces are somewhat rough, as each strip acts independently of the others. An auxiliary contact finger that does not leave its contact until after the main contact is opened is provided to break the final arc. When an excessive current flows through the operating coil *v*, the armature *g* is attracted and pulled down; this, in turn, depresses the upper end and raises the lower end of a releasing lever *f*. When the switch lever is released by the action of lever *f*, the parts of the breaker are snapped to the off-position. When the breaker is operated by hand by pressing on the tripping button, the plunger attached to the button presses on the right end of armature *g* and opens the breaker through the action of lever *f* and the switch arm.

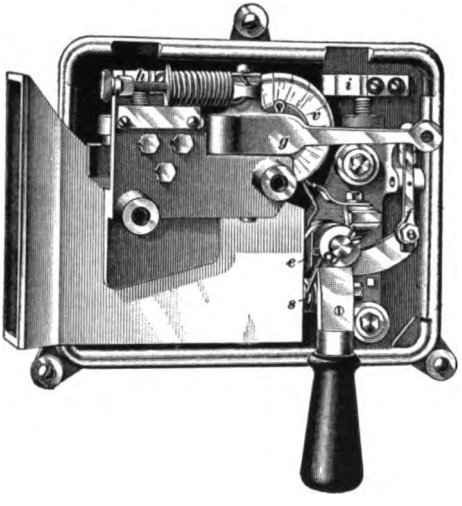

FIG. 50

The circuit-breakers used on multiple-unit cars are quite similar in design to the contactors, or unit switches, used in connection with the multiple-unit systems of speed control and are described in the Sections relating to those systems.

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MOTOR RHEOSTATS

59. In Fig. 51 is shown a General Electric type of **grid rheostat** used on an electric car to regulate the speed of the car when starting. Fig. 52 (*b*) shows the shape of the cast-iron grid, and (*a*) the zigzag path of the current through the grids. The grids *a* are assembled on insulated studs *b*, end plates *c*, Fig. 51, being then put on and the whole compressed into a solid mass by drawing up on nuts *d* at both ends. The feet *f* are for hanging the coil from the car floor. On the middle stud *b*, Fig. 52 (*a*), all the grids are separated from each other by mica insulating washers *c*. On the two outside studs *b*, however, considering any two adjacent grids, they touch each other on one stud, but on the other stud they are separated by a mica washer. The current entering at one end *d* is thus compelled to take a zigzag path to the other end *e*, as shown by the arrows. The coil shown represents the unit starting coil used in heavy traction work, a complete starting coil of any desired capacity being composed of the required number of unit starting coils connected either in series or in parallel, or both. The coil used on smaller single cars is of the same construction, but is longer and may contain several sizes of iron.

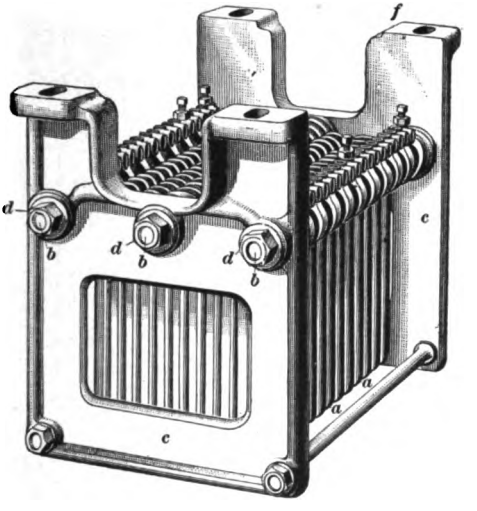

FIG. 51

60. In Fig. 53 is shown a Westinghouse grid rheostat. This rheostat embodies the same general principles as the

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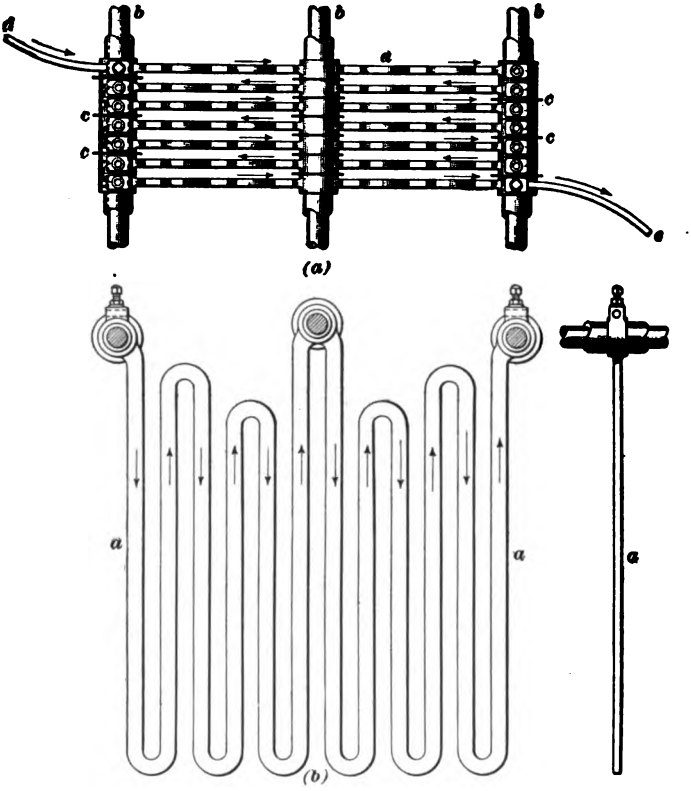

FIG. 52

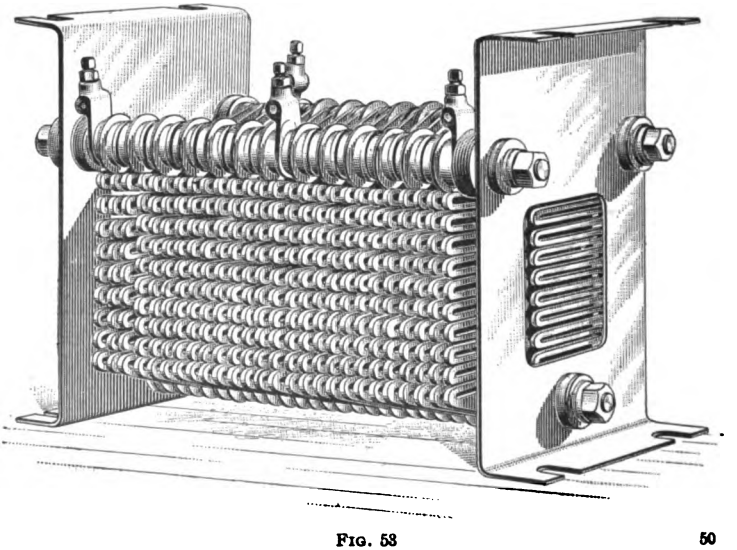

FIG. 53

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one just described, but differs slightly in details of construction. Although the rheostat is built compactly, the path for the current is long and thus the desired resistance is obtained. Various sizes of grids are used, depending on the capacity of the motor.

LIGHTNING ARRESTERS

LIGHTNING-ARRESTER PRINCIPLES

61. A varying electric current is surrounded by moving lines of force, and any conductor cut by lines of force has induced in it an electromotive force independent of any electromotive force already existing in the conductor. Any electrical disturbance that may take place in passing clouds sends out lines of force that cut trolley wires, feed-wires, etc., and that induce in them an electromotive force. Also, a cloud highly charged with electricity, whether it be stationary or moving, near a conductor will induce in the conductor a static charge that may raise the conductor's potential enormously. Whether the electromotive force induced in a conductor be due to electromagnetic induction or to electrostatic induction, it is, in general, said to be due to induction, and the electromotive force due to induction may be many times greater than the normal or working electromotive force of the conductor.

Assuming that the conductor in question is the trolley wire of a ground-return system, both the normal electromotive force and the induced electromotive force, when there is any, tend to cause current to flow to the ground. The normal electromotive force ordinarily causes current to flow through whatever working circuits may be established between the trolley wire and the ground; and if all working circuits be interrupted by switches or other devices, the normal electromotive force can cause no current flow, because it is insufficient to force current across an air gap. The electromotive force due to induction, for example, to

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lightning striking the line or some object near it, has no such limitations; in fact, an inductive discharge prefers an air gap to an ordinary working circuit, and it is to this preference that **lightning arresters** owe their effectiveness.

62. Appreciable time is required for the current to reach maximum value when an electromotive force is applied to a circuit of considerable self-induction. In Fig. 54, a trolley wire is shown at *t t*. A conductor connected to the trolley wire is wound into a coil *b* whose lower end is grounded at *g*. The beginning *a* and end *c* of coil *b* are brought close together at *d*, which represents a thin air gap between *a* and *c*. Any ordinary electromotive force, such as that of a trolley line, when impressed on the terminals of the coil will gradually force a maximum value of current through the coil in preference to jumping to the ground across the air gap at *d*; but the high electromotive force due to lightning or to an inductive charge is capable of jumping current across the air gap and will do so in preference to forcing current through the coil against its self-induction.

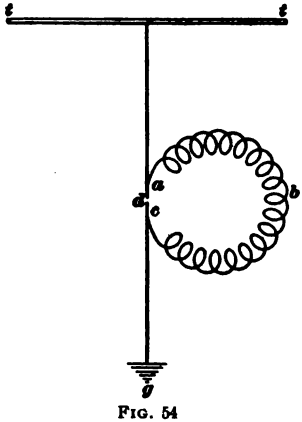

FIG. 54

To reach the ground, a lightning discharge will take a non-inductive path, if such is available; if not, the enormous voltage behind a lightning discharge enables it to create a non-inductive path. If lightning discharges into an electric circuit and finds no non-inductive path to the ground, it will jump through some part of the circuit's insulation, thereby creating a non-inductive path. The object of a lightning arrester is to provide a non-inductive path through which the lightning can reach the ground without doing any damage to the circuit or apparatus connected to the circuit. In its simplest form, a lightning arrester consists of two metal

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plates separated by a thin air gap; one plate is connected to one side of the circuit to be protected, and the other plate to the ground, as indicated in Fig. 55, where a trolley wire is shown at *t*, a motor circuit to be protected at *s–a–f–g*, and a lightning arrester at *LA*.

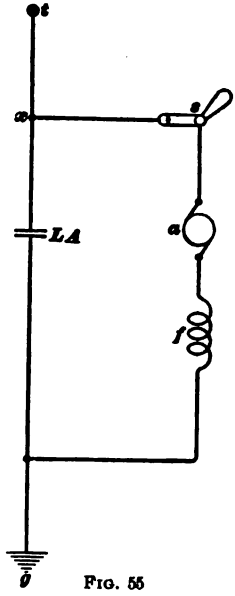

FIG. 55

63. When the potential of an electric-railway line rises to several thousand volts, the lightning arresters, if in good order, will pass a spark to the earth, thereby lowering the line pressure and relieving the tension; but if a lightning bolt, such as jumps $\frac{1}{4}$ mile or more through the air to splinter a tree or a house, actually strikes a car, it is probable that damage will be done, even though the arrester acts partly to relieve the tension.

The insulation of railway motors is tested to about 4,000 volts at the factory; that is, one side of a 4,000-volt test circuit is applied to some copper part of the motor and the other side to the motor frame or armature shaft. There is nothing between the two sides of the test circuit except the motor insulation, and the high electromotive force will cause a current to jump through any weak place in the insulation. After an equipment has been run for a time and dust and grease have accumulated on its parts, or after it has been allowed to stand in a damp car house for several weeks, its insulation will not stand so much pressure as when dry and new.

The lightning arrester should be so constructed and adjusted that it will allow a spark to pass to ground long before the line potential reaches 4,000 volts; otherwise, some part of the motor insulation will pass a spark that the trolley voltage can force a current to follow with disastrous results. The spark, consisting of metal vapor, acts as a conductor, so that it requires only a low electromotive force to maintain

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the arc. In lightning arresters having only a single air gap, the gap is usually adjusted to about $\frac{1}{10}$ inch, which will pass a spark when the line potential reaches about 1,500 volts. Other lengths of air gaps, however, are sometimes used.

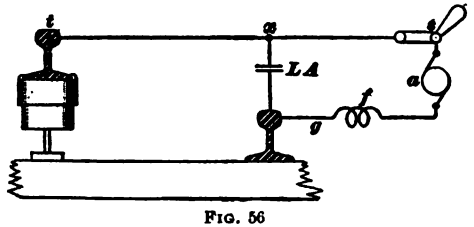

FIG. 56

64. On ground-return circuits, only the positive side of the circuit need be protected, as indicated in Figs. 55 and 56, where *s–a–f–g* shows the motor circuit to be protected from discharges liable to come in on the trolley wire or the third rail *t*. Lightning discharges arriving at tap *x*, jump the air gap *LA* rather than pass through the inductive motor circuit *s–a–f–g*.

65. A coil consisting of a few turns of wire in series with the motor circuit is shown at *k*, Fig. 57. The self-induction of the motor circuit is ordinarily sufficient to prevent the lightning discharge from passing to ground through the motor windings, but the self-induction of coil *k* is supposed to choke the lightning discharge back before it gets to the motors; hence its name, **choke coil.** Care must be taken to connect the choke coil in series with the motor circuit, and not in series with the arrester. With the protection of a choke coil and a lightning arrester, the discharge is supposed to pass from the line through the two switches s_1 and s_2, the fuse box *FB*, and the

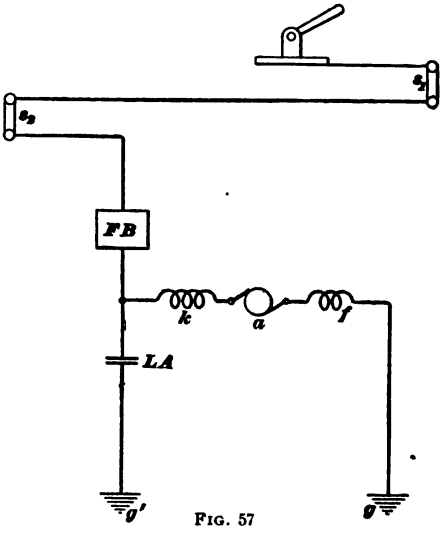

FIG. 57

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lightning arrester LA to the ground at g', although under abnormal conditions, a discharge may take place through the insulation of the motor to the ground.

TYPES OF LIGHTNING ARRESTERS

66. A type of Westinghouse lightning arrester suitable for use with direct-current and alternating-current circuits at any voltage up to 1,000 volts is shown in Fig. 58. The ground wire is connected to one terminal plate on a cylindrical carborundum block, and the line terminal is connected to a spark point located a short distance from a terminal plate on the other side of the block. The discharge due to lightning jumps the gap and spreads itself over the carborundum block along a number of minute discharge paths. The nominal voltage of the line is not sufficiently high to maintain arcs across these small air gaps, and, thus, after the discharge has passed to ground, the arrester again assumes its normal condition. In Fig. 59 is shown the general arrangement of this type of arrester. The carborundum block of the lightning arrester is protected from dampness or dust by the enclosing case.

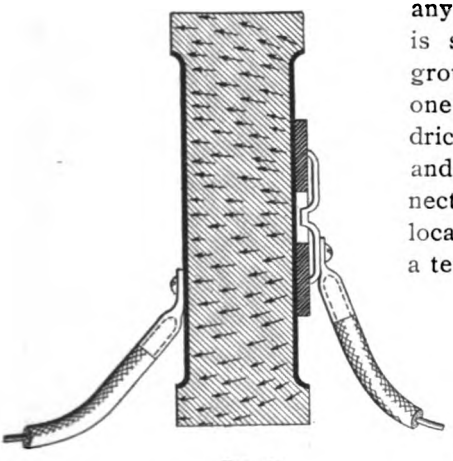

FIG. 58

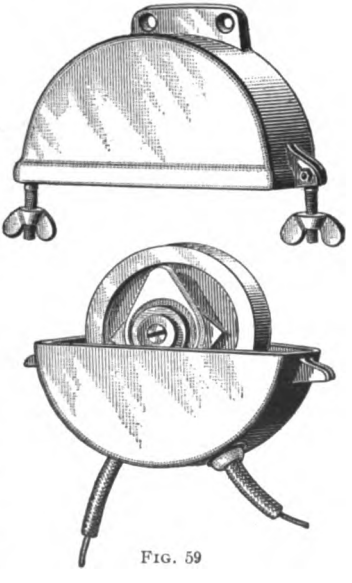

FIG. 59

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Choke coils are not used in connection with this lightning arrester on multiple-unit cars, because the magnetic blow-out coils in the switch group of the car equipment serve the same purpose.

67. With Westinghouse single-phase railway equipments, it is the practice not to use arresters on the cars, but to install lightning arresters of the **fuse type** on poles and to connect these arresters at frequent intervals to the trolley wire. A type of fuse arrester for potentials not exceeding 11,000 volts is shown in Fig. 60. When the trolley wire near one of these arresters receives a very high charge, a spark jumps across the spark gap *a* and the trolley current immediately follows, passing through the fuse *b* to the ground. The fuse wire in the lignum-vitæ tube melts, releasing the trigger *c* and allowing the fuse holder *d* to swing clear of the lower part of the arrester frame. Thus, the trolley wire will not be grounded through the arrester after the discharge has passed.

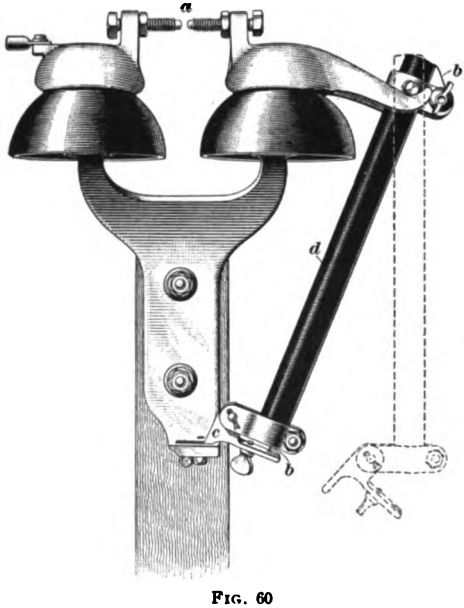

FIG. 60

As there are a number of arresters connected to the trolley wire, the line will still be protected even if a few of the arresters may be out of service due to their fuses having been blown. By means of a pair of wooden fuse tongs, the fuse tube may be removed. A new fuse wire is then inserted and the tube replaced.

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68. In many cases where the current is taken exclusively from a third rail, no arresters are used on the cars. In Fig. 61 is shown the **General Electric type M, form D-2 arrester.** This type of arrester is used extensively on cars operated by direct current where danger exists of damage due to lightning. The spark-gap terminals *a* are mounted on the cover of the porcelain box. When the cover is in position, the air gap is between the pole pieces *b* of the blow-out magnet *c*. The magnet is in shunt with a portion of the non-inductive resistance *d*.

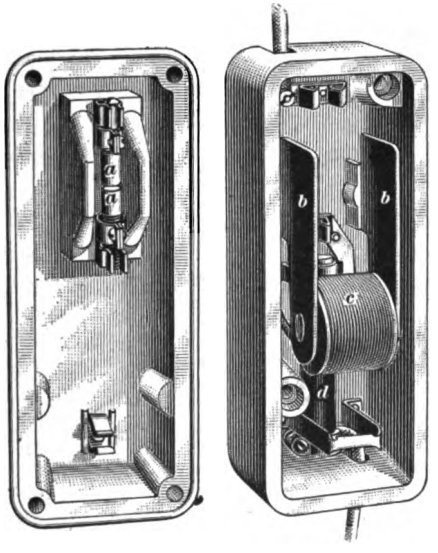

FIG. 61

The connections for an arrester of this type are shown in Fig. 62. The normal path of the motor current is *t–FB–t'–k–a–f–g*; it does not pass through the arrester because of the air gap at *LA*. When a lightning discharge reaches the choke coil *k*, rather than pass through the inductive path of the choke coil and motor circuit, it jumps the air gap *LA* and takes the non-inductive path *LA–n–z–r'–r–g* to the ground. It does not take path *LA–n–x–c–y–p–r–g* because the blow-out coil *c* has too much self-induction.

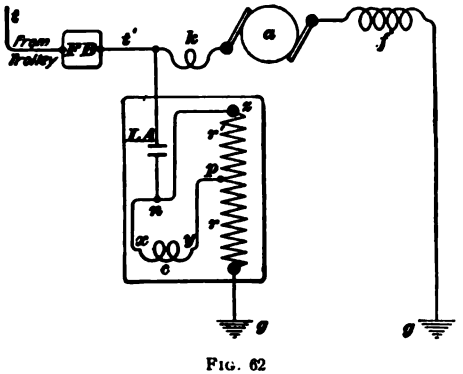

FIG. 62

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As soon, however, as the discharge jumps the air gap, the after current takes path *t–FB–t'–LA–n–x–c–y–p–r–g* to the ground. A large portion of the after current passes through the low ohmic resistance of coil *c* in preference to the high ohmic resistance in section *r'*, which is in parallel with *c*. The coil *c* does not offer so high an electromotive force of self-induction to the passage of the trolley current as it does to the passage of the current due to the sudden lightning discharge; therefore, the trolley current can easily flow across on the spark formed at *LA* and through coil *c*. Both the discharge and the after current pass through section *r* of the resistance, which therefore limits the value of the

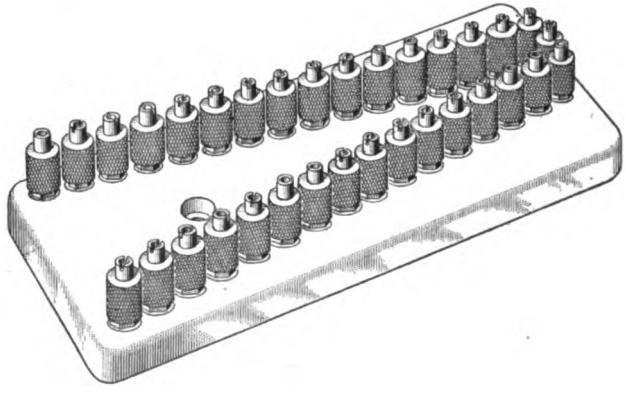

FIG. 63

after current. The flow of after current through the magnetic blow-out coil *c* causes it to project a magnetic field between the spark points, with the result that the arc is repelled and broken.

69. For high-tension, alternating-current work, the General Electric Company often use a lightning arrester of the **multigap type** on the line wires and the cars. The exact form and the connections of the apparatus depend on the requirements of the installation. Several knurled metal cylinders are set a short distance apart on a porcelain base, and in some cases the gaps between a group of cylinders are

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shunted by a resistance. The lightning discharge causes sparks to jump across the gaps between the cylinders. The current from the alternators at the station follows, but as the alternating current passes through zero value, the arc vapor in the gases cools to a non-conducting state, and with the aid of the resistance, which forms a shunt around some of the gaps, the arc cannot again set itself up after the normal current has reversed. Fig. 63 shows a V unit of a multigap lightning arrester, with the top porcelain cover removed.

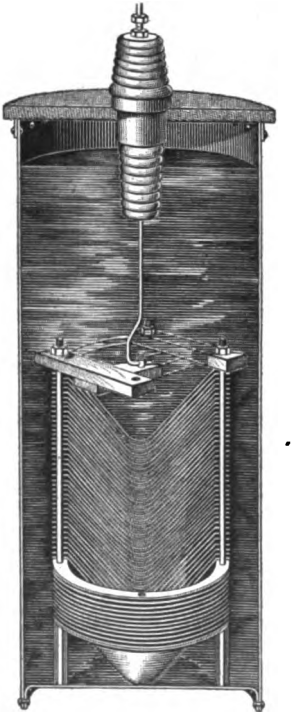

FIG. 64

70. The aluminum electrolytic lightning arrester is manufactured by several of the large electrical companies. It consists of a series of concentric, inverted, aluminum cones placed one above the other with a vertical spacing of about .3 inch, as shown in Fig. 64.

The electrolyte partly fills the spaces between the cones. The stack of cones with the electrolyte between them is immersed in oil in a steel tank. A very thin insulating film is formed on the surface of each aluminum cone. At ordinary electromotive forces, the film prevents all but a slight leakage current from passing; but if the electromotive force is increased to more than 420 volts for each cell (composed of two cones and the electrolyte between them), the film opens up like a safety valve and allows a discharge to pass. For high-tension lines, the stack consists of a large number of cells.

After normal conditions again obtain, the film builds up again and prevents all but the small leakage current from

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flowing. In order to prevent this leakage current, a horn spark gap is often placed between the aluminum cells and the line. The lightning charge must then jump the gap as well as pass through the cells when discharging to the ground.

CAR STORAGE BATTERIES

71. In Fig. 65 is shown one set of small **storage batteries** used with the Westinghouse multiple-unit systems

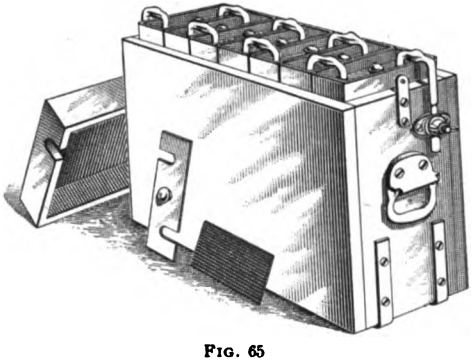

FIG. 65

for furnishing current for the control circuits. There are two sets to each car, and one set may be charging while the other set is in active service.

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TYPES OF RAILWAY MOTORS

DIRECT-CURRENT MOTORS

PRELIMINARY CONSIDERATIONS

1. Requirements.—Electric-railway motors have to meet several conditions not imposed on motors used for stationary work. They must be compact, in order that they may be mounted beneath the car; practically dust-proof and waterproof, since they are in an exposed situation; and substantial in every particular, because, with few exceptions, they are subjected to harder usage than any other kind of electrical machinery.

Practically all railway motors are of the series-wound type. For this service, a motor must give a strong starting effort and an increasing torque with decreasing speed. All current that flows through the armature also flows through the field coil; therefore, a very powerful magnetic field is obtained when the motor is starting. Variable speed is essential for railway operation. Series-wound motors conform to this condition, but the shunt-wound motor is essentially a constant-speed machine; hence, it has never been used to any extent for this class of work.

2. Speed Reduction.—It has not been found practicable or economical to drive ordinary electric cars by means of motors having their armatures mounted directly on the axles, though such motors may be used to advantage in special cases when they are of large size, as, for example, on heavy,

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high-speed, electric locomotives. For ordinary work, motors are always geared to the axle; a pinion on the armature shaft engages with a gear keyed to the axle, both gears being covered by a gear-case that contains a quantity of heavy oil. The reduction in speed depends on the relative number of teeth in the two gears; the smaller the pinion, as compared with the gear, the greater will be the reduction.

TABLE I

REVOLUTIONS OF CAR AXLE CORRESPONDING TO VARIOUS CAR SPEEDS

Speed of Car Miles per Hour	Speed of Car Feet per Minute	Speed of Car Axles (Revolutions per Minute)						
		30-Inch Wheels	31-Inch Wheels	32-Inch Wheels	33-Inch Wheels	34-Inch Wheels	35-Inch Wheels	36-Inch Wheels
6	528	67.2	65.0	63.0	61.1	59.3	57.6	56.1
8	704	89.6	86.7	84.0	81.5	79.1	76.8	74.7
10	880	112.0	108.4	105.0	101.8	98.9	96.1	93.4
12	1,056	134.4	130.0	126.0	122.2	118.6	115.2	112.1
14	1,232	156.9	151.7	147.0	142.6	138.4	134.5	130.7
16	1,408	179.2	173.4	168.0	163.0	158.2	153.6	149.4
18	1,584	201.7	195.1	189.0	183.4	178.0	172.9	168.1
20	1,760	224.0	216.8	210.0	203.7	197.8	192.1	186.8
22	1,936	246.5	238.4	231.0	224.1	217.5	211.3	205.5
24	2,112	268.8	260.0	252.0	244.4	237 3	230.4	224.2
26	2,288	291.3	281.8	273.0	264.8	257.1	249.7	242.9
28	2,464	313.8	303.4	294.0	285.2	276.8	268.9	261.4
30	2,640	336.1	325.1	315.0	305.6	296.6	288.2	280.2
32	2,816	358.4	346.8	336.0	326.0	316.4	307.4	298.8
34	2,992	380.9	368.4	357.0	346.3	336.2	326.6	317.6
36	3,168	403.4	390.2	378.0	366.7	356.0	345.8	336.2
38	3,344	425.8	411.8	399.0	387.1	375.7	365.0	354.9
40	3,520	448.0	433.6	420.0	407.4	395.6	384.2	373.6
42	3,696	470.6	455.2	441.0	427.8	415.3	403.5	392.3
44	3,872	493.0	476.8	462.0	448.1	435.1	422.6	411.0
46	4,048	515.4	498.5	483.0	468.5	454.8	441.9	429.7
48	4,224	537.6	520.0	504.0	488.8	474.6	461.1	448.4
50	4,400	560.2	541.8	525.0	509.2	494.4	480.3	467.0

The **gear-ratio** of an equipment will here be understood as the ratio of the number of teeth in the gear to the number in the pinion; this is the more usual way of expressing it,

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though it is sometimes given as the ratio of the number of teeth in the pinion to the number in the gear. The pinion has, in nearly every case, fewer teeth than the gear, so that there is little cause for confusion no matter which way the ratio is stated. If, then, a motor has 14 teeth in the pinion and 68 in the gear, the gear-ratio is $\frac{68}{14} = \frac{4.86}{1}$ and the motor armature runs 4.86 times as fast as the axle. Table I gives the speed of car axles, in revolutions per minute, for different car speeds and diameters of wheels. By multiplying the revolutions given in the table by the gear-ratio in any given case, the speed of the motor armature is obtained.

EXAMPLE.—A car is mounted on 33-inch wheels and runs at a speed of 20 miles per hour; how many revolutions per minute do the motor armatures make if there are 65 teeth in the axle gear and 15 in the pinion?

SOLUTION.—The speed of the car axle, Table I, for 33-in. wheels and a speed of 20 mi. per hr., is 203.7 rev. per min. The gear has 65 teeth and the pinion 15, hence the gear-ratio is $\frac{65}{15} = \frac{4.33}{1}$. The speed of the armature is, therefore, $203.7 \times 4.33 = 882$ rev. per min., approximately. Ans.

3. Nominal Rating of a Railway Motor.—It is customary usage to give railway motors a nominal rating in horsepower on the basis of a 1-hour test. A simple rating of this kind is not strictly an accurate measure of service capacity, but it does indicate approximately the maximum output that the motor should ordinarily be called on to develop during acceleration.

The nominal rating of a railway motor is the horsepower output of the motor at the car axle that will give a rise of temperature above the surrounding air (referred to a room temperature of 25° C.) not exceeding 90° C. at the commutator and 75° C. at any other part of the motor after 1 hour's continuous run at its rated voltage on a stand, with the motor covers removed and with natural ventilation.

The horsepower at the axle is less than the horsepower at the armature pinion, owing to the transmission losses in the

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motor gears. The car-journal friction is not considered in this method of rating the motor. In the case of alternating-current railway motors, the frequency of the current in the testing lines should be the same as the rated frequency of the motor. The rise in temperature is determined by means of a thermometer, but the resistance of no electrical circuit in the motor shall increase more than 40 per cent. during the test.

If the room temperature during the test differs from 25° C., a correction on account of difference in resistance should be made by changing the observed rise of temperature by $\frac{1}{2}$ per cent. for each degree centigrade difference in temperature from the standard. Thus, with a room temperature of 35° C., the observed rise of temperature of the motor will have to be decreased by $(35 - 25) \times \frac{1}{2} = 10 \times \frac{1}{2} = 5$ per cent. With a room temperature of 15° C., the observed rise in temperature of the motor will have to be increased by $(25 - 15) \times \frac{1}{2} = 5$ per cent. With these corrections, the temperature of the motor must not exceed the stated limits.

4. **Continuous Capacity of a Railway Motor.**—The continuous capacity of a railway motor is given in terms of the amperes that it will carry continuously when run on a testing stand—with covers on or off, as specified—at different voltages, say 40, 60, 80, and 100 per cent. of the rated voltage (the test is usually made at 300 or 400 volts), and with a temperature rise not exceeding 90° at the commutator and 75° at any other part (referred and corrected for a room temperature of 25° C.), provided the resistance of no electric circuit in the motor increases more than 40 per cent.

DESCRIPTION OF FOUR-POLE MOTORS

DETAILS OF CONSTRUCTION

5. Electric-railway motors consist of several well-defined parts, including the *frame*, the *field coils*, the *armature*, the *brush holders*, and the *bearings*.

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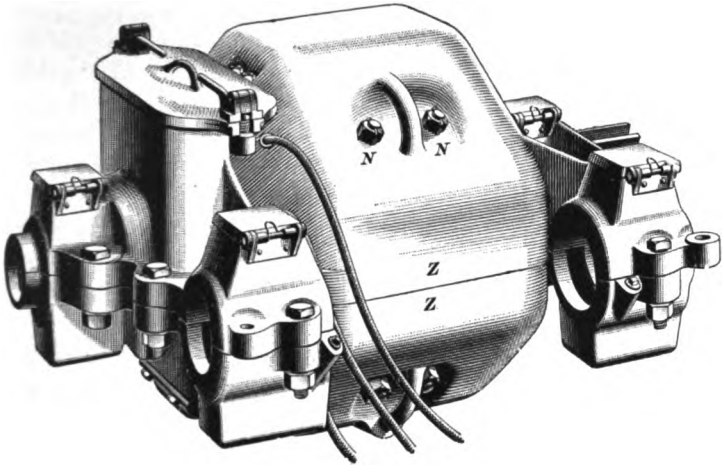

FIG. 1

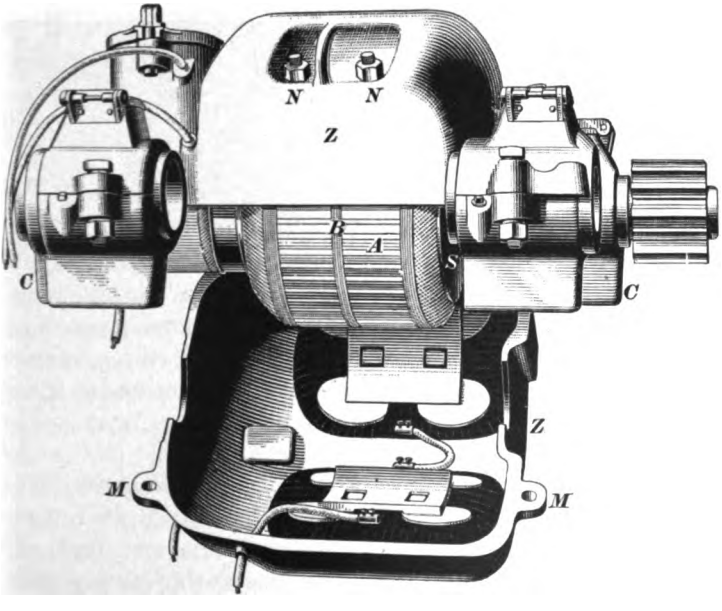

FIG. 2

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6. Frame.—The **frames** of the smaller electric-railway motors are usually in two parts, which are hinged together as shown in Figs. 1, 2, and 3. When the motor is closed, as shown in Fig. 1, the halves Z are held together by two links, one of which is shown at e, Fig. 3, and by two bolts passing through holes m, Fig. 2, and corresponding holes in the upper frame. The link e, Fig. 3, passes between the upper lugs a, a' and through the lug on the lower part of the frame. The hinge pin B passes through link e and lugs a, a'; nut n serves to clamp the parts of the frame together.

To lower the bottom half, the hinge bolts are loosened and the bolts through m, Fig. 2, are removed. The lower half will then swing down, thus exposing the lower field

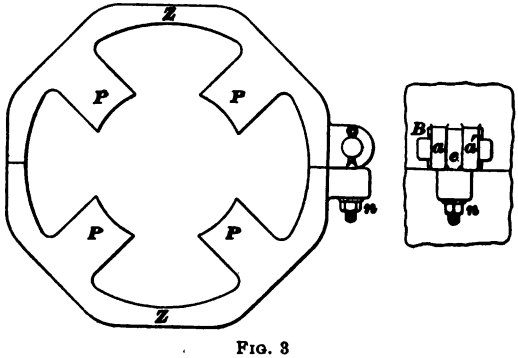

FIG. 3

coils. If the bolts that secure the armature caps C, Fig. 2, to the top half of the frame are left in, the caps hold the armature up so that the lower half of the frame goes down without it; but if these bolts are removed, the armature remains in the lower half. This arrangement is incorporated in most motors whose frames are cast in halves, and is very convenient, because either a top or a bottom field coil can be got at without handling the armature, or the armature can be removed without disturbing any of the field coils. To remove a top field, the lower shell is let down with the armature; and to remove a lower field, the armature is left in the top shell.

There are four pole pieces bolted to the frame by means of bolts N, Figs. 1 and 2. Handholes in the frame are provided

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for inspection purposes and for removing carbon and copper dust or any dirt that may enter the frame.

7. Field Coils.—There is usually one **field coil** on each pole. The coils are wound on a wooden form and are so insulated that they are nearly waterproof. The field coils of many of the modern motors are insulated by the vacuum process, as follows: The coils are placed in an iron tank and the air is then exhausted; after this, insulating compound from another tank is allowed to flow into the tank containing the coils. The coils are thus impregnated with the compound. Outside wrappings of tape are then put on the coils

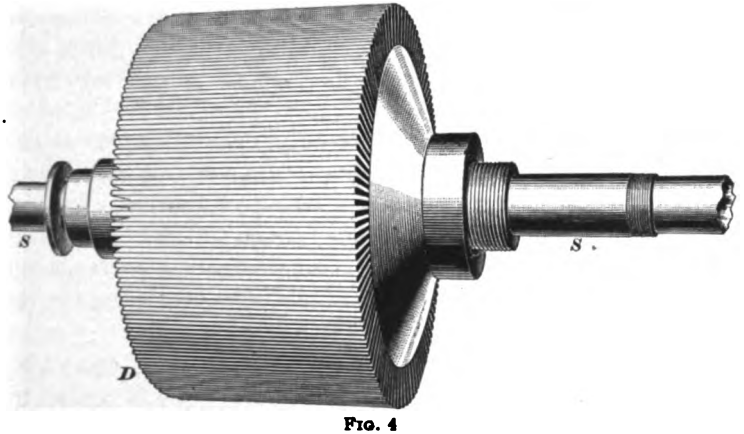

FIG. 4

and these wrappings are filled with japan. The coils are thus protected from mechanical injury and from water.

The motor frame is practically waterproof, but there are some conditions under which water may enter. Therefore, the field-coil insulation must be carefully prepared.

8. Armature.—The **armature** *A*, Fig. 2, consists of several parts, among which are the core, the commutator, the shaft, the winding, the shield, and the band wires. An armature core mounted on a shaft is shown in Fig. 4. The core is built up of toothed iron disks *D*, keyed to the shaft *S S*, and clamped against a shoulder and end plate at one end

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of the core by means of an end plate and nut at the other. The disks are provided with a number of teeth, and when assembled on the shaft, a corresponding number of slots are formed. The wire is wound into coils on forms, and the

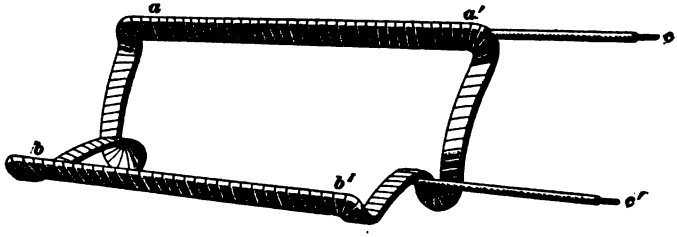

FIG. 5

coils are made to hold their shape by binding them with tape. Fig. 5 shows the shape of a coil suitable for the core shown in Fig. 4. The straight portions $a\,a'$, $b\,b'$, Fig. 5, lie in the slots, and the ends are given the shape shown, so that the different coils may cross each other without interfering. The terminals c are connected to the commutator. In most of the four-pole, direct-current railway motors, a series-wound armature is used; thus, only two brushes per motor are needed, and these are placed near the top of the commutator where they may be easily inspected.

When an armature turns, the wires tend to fly out of the slots on account of the centrifugal force and the drag that the pole pieces exert on them. To hold them in place, bands B, Fig. 2, and the shield S are provided. The bands in this case are three in number, and consist of eighteen or twenty turns of No. 16 or 18 B. & S. gauge phosphor-bronze or steel wire, secured by clips of sheet copper laid under the turns and then bent over, as shown in Fig. 6. The whole surface of the band is then soldered. The shield is either a brass or an iron cap curved to fit the shape of the ends of the coils and screwed on to a shoulder on the shaft. This shield has an insulating washer on the inside, so that it cannot bruise the coils when screwed home. If the shield is left off, the coils must be tied to the shaft, or they may rise.

FIG. 6

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9. Commutator.—The principal parts of a **commutator** are the bars, the mica rings and bodies, the iron rings and nuts, and the shell. The copper bars, or segments, are made of either hard-drawn or drop-forged copper and are of uniform quality, so that the commutator will wear evenly. The mica bodies are of the same shape and number as the bars, one body going in between every two bars, so that the bars cannot touch each other. The mica selected must wear at the same rate as the copper; otherwise, the commutator will become rough. The mica bodies must have a certain thickness relative to that of the bar, or the wear will be bad. Fig. 7 (*a*) shows how the commutator wears when the mica bodies are too soft or too thin, and Fig. 7 (*b*) shows how it wears when the bodies are too hard or too thick. In either case, the brushes spark badly.

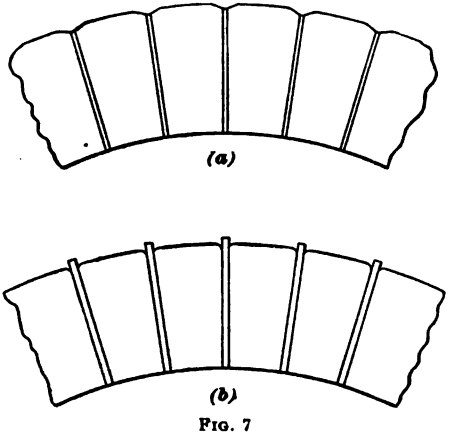

FIG. 7

10. Fig. 8 shows the parts of a railway-motor commutator. At (*a*) is shown the shell, made of steel, brass, or malleable iron, so that it will not crack when it is put under the pressure necessary to hold the bars and bodies in place; at (*b*), a mica cone ring that fits on to the head of the shell, as shown at *b* in the assembled view; at (*c*), a mica sleeve that slips under the segments, as shown at *c* in the assembled view; at (*d*), a metal cone ring that goes on to the shell to form its other head, and, after receiving a mica cone ring like (*b*), is shoved home against the end of the bars and bodies by means of a nut (*e*) that threads on to the shell (*a*). One of the bars is shown at (*f*), and (*g*) shows one of the mica bodies used between them. The assembled view (*h*)

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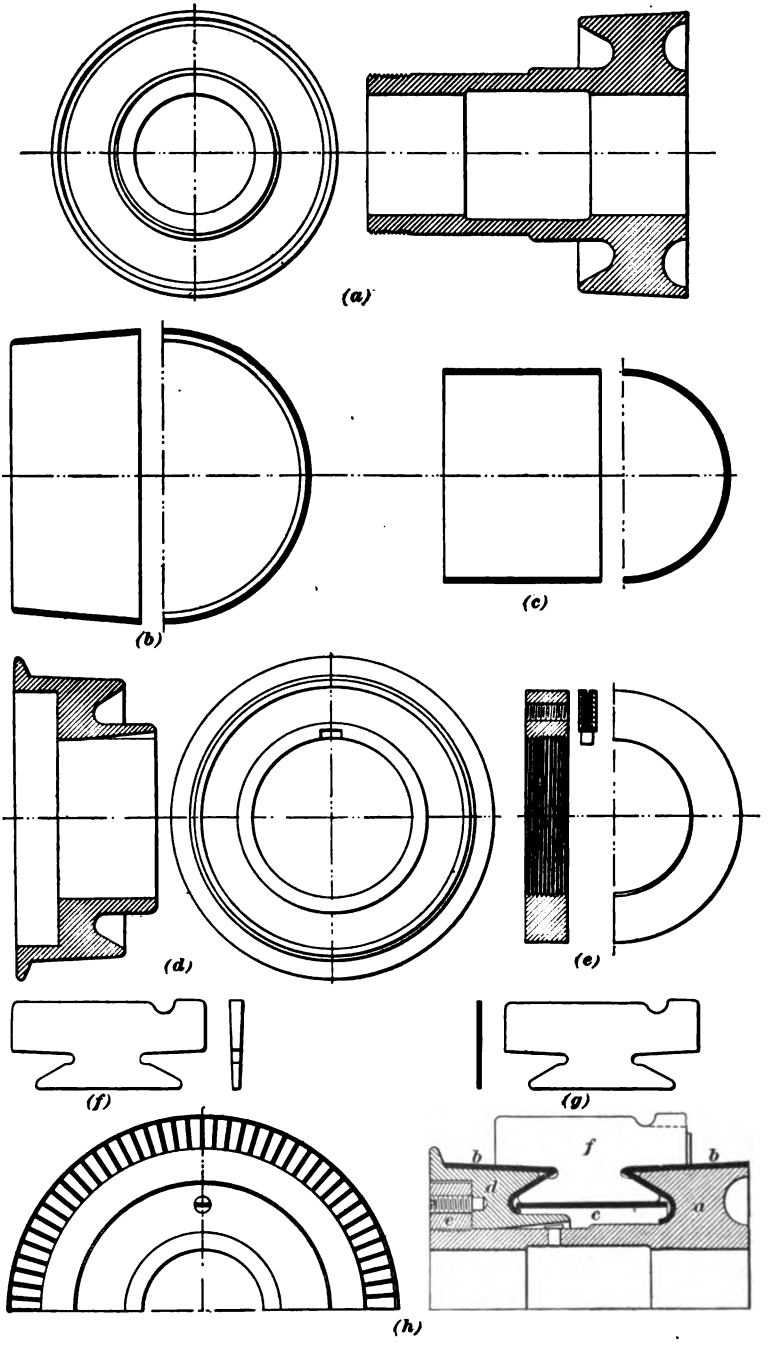

FIG. 8

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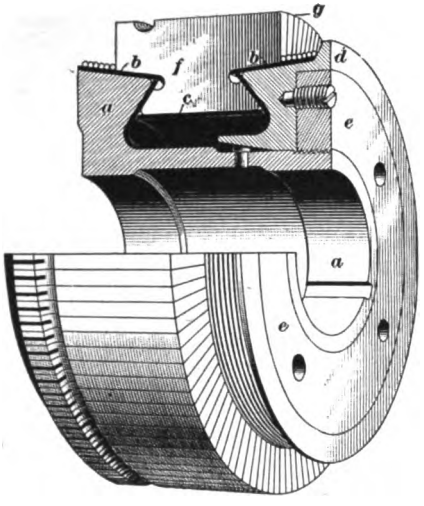
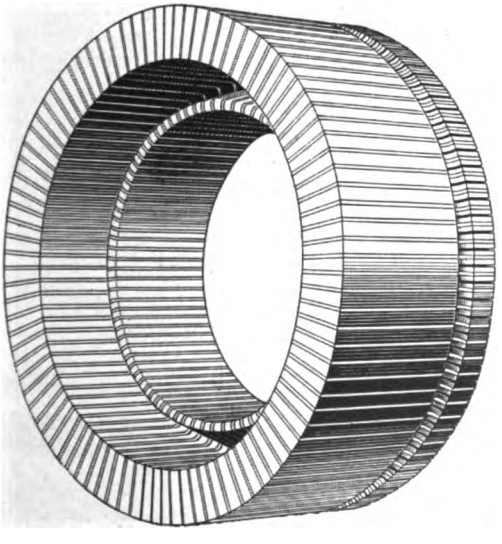


(*a*)



(*b*)

FIG. 9

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shows the location of the various parts after the commutator is put together. Fig. 9 (*a*) shows the several parts in place, and indicates the method of construction, while (*b*) shows the mica bodies and copper bars ready to be put on the shell.

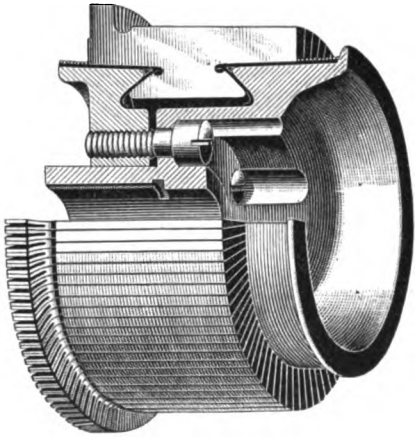

FIG. 10

Fig. 10 shows the method of construction of a commutator for a GE-207 commutating-pole railway motor.

11. Brush.—Fig. 11 shows the type of carbon **brush** used on modern railway motors. The brushes are made of carbon because these spark less than copper brushes, owing to the comparatively high resistance of carbon, which prevents an excessive flow of current in the coils temporarily short-circuited by the brushes.

12. Brush Holder.—Fig. 12 shows one type of **brush holder.** In this figure, *A* shows the commutator; *B*, the motor brushes; *H*, the brush holders proper, made of brass; *W*, a wooden yoke that fastens to the motor frame by means of a casting, not shown; *N*, slots; and *M*, bolts provided for clamping the brush holders at any desired distance from the commutator. The two brush leads *L* have brass terminals that are also secured by bolts *M*. The wooden yoke is made of well-seasoned maple boiled in paraffin to make it moisture proof. It is then treated with insulating compound and rubbed smooth, so that it will hold no carbon dust or water on its surface. At *S* are shown two tension springs that pull down on fingers *F* and press the brushes against the commutator. The brushes point to the center of the

FIG. 11

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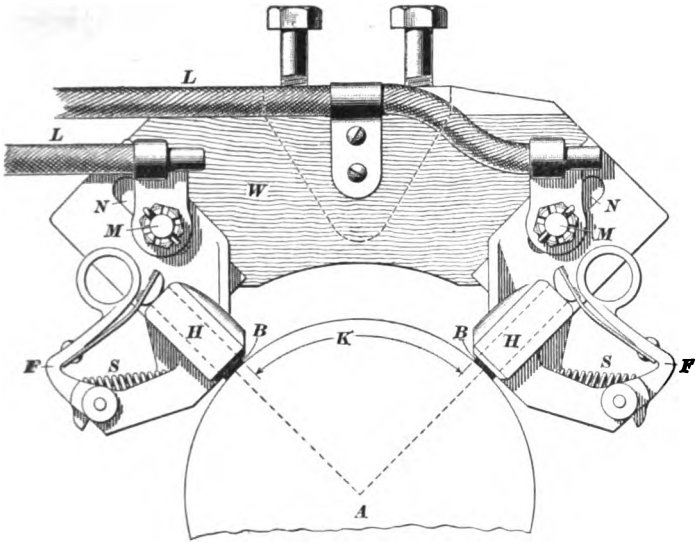
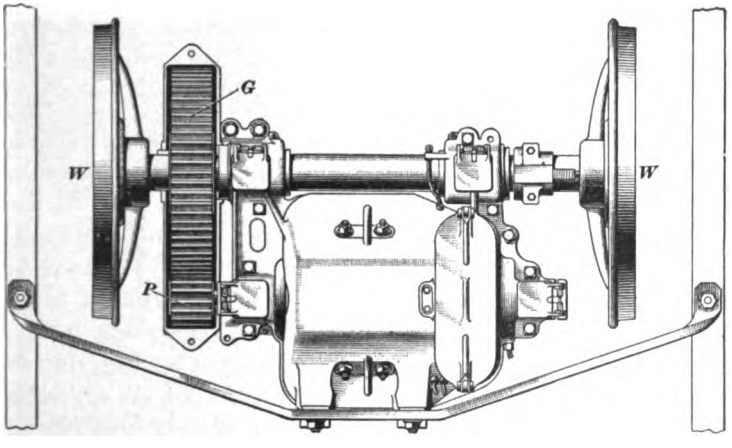


FIG. 12



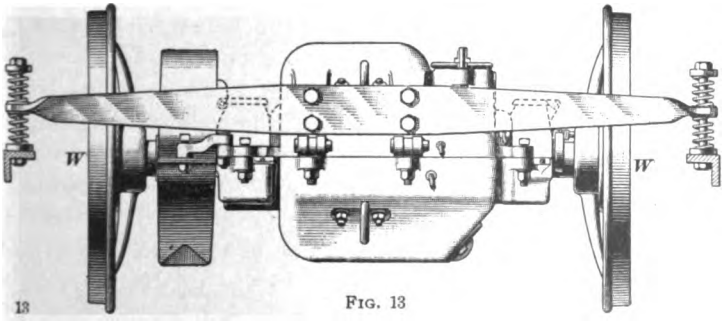


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FIG. 13

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commutator whatever may be its diameter, which decreases with wear. The brushes are set on the quarter; that is, the distance from the center of one brush to that of the other along the surface of the commutator is one-quarter of the whole distance around the commutator. The angular space between the inside edges of the brushes is indicated at *K*.

13. Bearings.—There are two axle and two armature bearings of liberal dimensions. If the bearing is large in diameter and the shaft is built in proportion, there is little danger of the shaft being bent unless a bolt or part of a broken gear-tooth gets in between the gear and the pinion while the car is in motion. The axle bearings are interchangeable and admit of being babbitted and bored to any size up to 4 inches. **Babbitt** is a composition of tin, copper, and antimony. This composition is used extensively for lining bearings, because of its non-frictional qualities. The Babbitt metal is usually cast on the inside of the bearing sleeve, which is then bored to fit the shaft.

14. Gearing.—Fig. 13 shows one method of connecting a railway motor armature to the car axle. In this figure, *P* shows the small gear, called a *pinion*, forced on to the tapered end of the armature shaft and secured by means of a nut and spring washer; while *G* shows the gear, made in two parts, as shown in Fig. 14, so that it can be put on or taken off without pressing off one of the car wheels *W*, Fig. 13. In one of the halves, a keyway *k*, Fig. 14, is cut to take a key set in the axle. This key is intended to keep the gear from turning on the axle, and all fitting having to do with it should be exact. The gear turns with the axle. On heavy equipments is used a solid gear that is pressed on the axle. The halves of the motor frame are shown in Fig. 13.

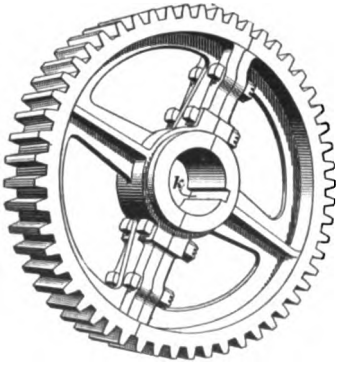

FIG. 14

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The springs at the side of the motor suspension bar, which rests on the truck, are intended to cushion the blows struck by the motor when the car is running over a rough track.

GE-73 MOTOR

15. In Fig. 15 is shown a **GE-73 railway motor** designed for high-speed interurban work, or to handle trains

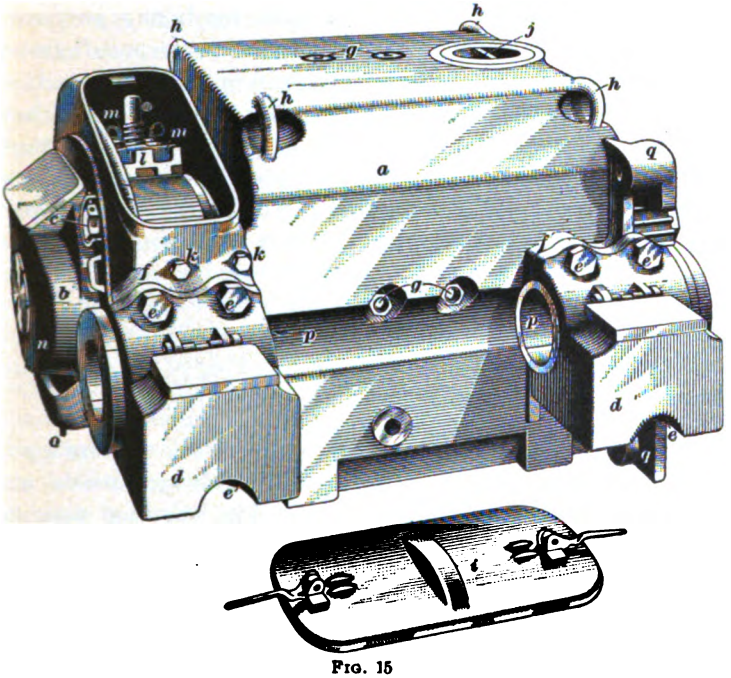

FIG. 15

made up of several motor cars under conditions requiring rapid acceleration and frequent stops. Its rated output is 75 horsepower.

16. Frame.—In Fig. 15, the frame, shown at *a*, is cast of soft steel in one piece, of cubical shape, with rounded corners. Large circular openings in each end of the frame casting receive frame heads *b*, which carry the armature bearings. The frame heads are secured to the frame by

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bolts *c*, of which there are four to each head. The armature is installed or removed through the circular opening on either end by removing the frame head on that end. Axle bearing caps *d* are secured to the frame, in a vertical plane, by bolts *e*, thereby minimizing the overhang of the planed cap bases *f*, and facilitating the raising or lowering of the motor. Four laminated pole pieces are secured to horizontal and vertical planed bases in the interior of the frame by bolts *g*. Forged bails *h* are provided for lifting purposes. A malleable-iron cover *i* provided with a waterproof gasket covers a large opening over the commutator. The inclination of this opening makes it practicable to reach the brushes, either from under the car or from inside, through the traps. An opening below the commutator and three side and top openings, similar to the one shown at *j*, further facilitate inspection of the interior of the frame. Where conditions permit, the bolted covers to these openings may be removed and additional ventilation obtained. The armature and field terminals are brought out through rubber bushings on the commutator end of the motor, in positions in which the swing of the terminals, when the car is rounding curves, will be least.

17. Field Coils.—The field coils—two large ones and two smaller ones—are wound on cast-bronze spools and insulated with mica and asbestos. The winding may be varied within certain limits to suit local conditions; a standard winding consists of eighty turns of flat copper ribbon, $1\frac{1}{8}$ in. × .08 in., on the large spools, and forty turns of 1 in. × .08 in. copper ribbon on the small ones, with asbestos ribbon wound between turns. The coils are bound with canvas impregnated with insulating compound. The finished coil is solid, compact, semifireproof, and practically waterproof. The spools have finished surfaces on the top and bottom that engage corresponding finished surfaces on the frame and pole pieces. When the pole-piece bolts *g*, Fig. 15, are forced home, the pole pieces and spools are drawn to true seatings.

18. Armature.—The end plate on the pinion end of the laminated core is made cup-shaped so as to form a solid

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surface, on which the armature coil ends may be anchored. The completed core has thirty-nine slots. Each individual coil has two turns, and three of these individual coils are grouped into a complete coil or cell, of which the armature has thirty-nine. The individual coils in a cell are insulated from each other, and the cell as a whole is well insulated. A complete cell is run into a combination steam press and mold. The heat softens the plastic insulation, and the pressure forces the parts that are to go into the armature slots to take almost the exact dimensions of the slot. The steam is then turned off and cold water is turned on; this renders the coil compact and hard. The heat generated by the motor in operation is insufficient to soften the coil. The armature windings at both ends are protected with canvas hoods that throw off water and also prevent an accumulation of carbon dust or grease between the leads.

19. Commutator.—The commutator contains 117 hard-drawn copper bars. The mica bodies are made soft enough to insure that they will wear down at the same rate as the copper bars. The shell and cap are of cast steel, and all coned surfaces are machined to gauge. The insulating cone rings and sleeves are pressed to gauge in steam molds, and are interchangeable on different commutators. The commutator bolts are screwed home while the commutator parts are subjected to hydraulic pressure.

20. Brush Holder.—The brush holders are made of cast bronze and are independent of each other, being seated to the motor frame on opposite sides of the commutator and secured by brush-holder bolts *k*, as shown in Fig. 15. The holder is shown at *l*. The brushes *m*, of which there are two to each holder, are forced into contact with the commutator by springs. Guides for the brushes are provided that insure a radial position for the brushes throughout their wear. The springs provide almost uniform tension throughout the working range of the brushes. A flexible copper shunt connects each brush to its holder, so that very little current passes through the tension spring or any of the pivotal

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parts. The brush holders are adjustable to allow for commutator wear.

21. Bearings.—The frame heads *b*, Fig. 15, are made of malleable iron cast in one piece. To secure maximum bearing surface, the frame heads, which are cone-shaped, extend well into the commutator shell and pinion-end armature head. Each head has an oil well *n* drained by a drain plug *o*. Wool waste packed into the oil well brings the oil up against the under side of the armature shaft through oil ways. The axle bearings *p* are lubricated in the same manner. The armature linings are unsplit bronze sleeves provided with a thin layer of Babbitt metal soldered to the bearing surface. This layer is so thin that should excessive heat cause it to run, the armature will not be let down on the pole pieces.

22. Gear and Housing.—The gear is of cast steel and the pinion is of forged steel. Several gear-ratios are used on this motor to meet varying conditions. The gear-housing, or gear-case, is made of malleable iron and is in two parts. The two parts are bolted together, and the gear-case is secured to the frame by stud bolts passing through lugs *q*.

23. Points of Design.—Good ventilation is obtained owing to the fanning action of the armature, to the open character of the windings, to the ducts provided especially to promote good circulation of air, and to the arrangement of the motor-frame covers, which may be left off when operating conditions permit. The box-frame construction is used, because it provides a better magnetic circuit than a split frame. The liberal use of stud bolts instead of nut bolts minimizes the chances of loose gear-cases or loose bearing caps.

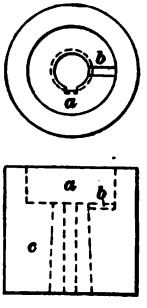

FIG. 16

One special feature of construction is the method used to prevent the armature pinion from backing off the tapered armature shaft. Fig. 16 shows a plan and elevation of a pinion bored to fit a tapered seat on the shaft. The outer end of the pinion is counterbored, as indicated at *a*, so that the pinion

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nut will not extend out beyond the pinion. A groove *b* is cut in the surface of the counterbore. The pinion *c* is placed on the shaft *d*, as indicated in Fig. 17. A steel washer *e* is slipped on the shaft. This washer is hammered into groove *b*, the nut *f* is then run on and screwed home, and one edge of the washer is turned up against the nut, as shown at *g*. The washer prevents the nut from turning, the pinion prevents the washer from turning, and the pinion key prevents the pinion from turning on the shaft.

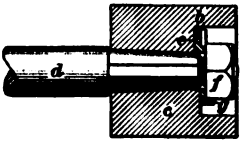

FIG. 17

WESTINGHOUSE 113 MOTOR

24. In Fig. 18 is shown the **Westinghouse 113 motor**, which has a rating of 200 horsepower. The frame is split at an angle of 45° with the horizontal, and the pole pieces are placed on vertical and horizontal diameters. The upper field may be lifted off and the armature removed without taking the motor from the truck, or the motor may be handled as a single piece by removing the gear-case and axle caps. The car body must be removed from the truck in order to handle the motor from above. When the two portions of the frame are bolted together, the armature bearings are held firmly in

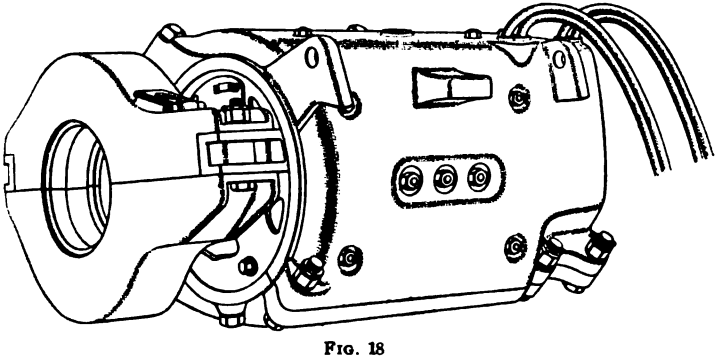

FIG. 18

place. Access to the brush holders and commutator is provided by a large opening, which is normally kept closed by

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a spring-locked cover in the commutator end of the frame; this extends down on one side, so that inspection can be made from the pit.

THEORY OF COMMUTATING-POLE MOTOR

EFFECTS OF ARMATURE REACTION

25. Many of the disorders developed during the operation of railway motors are due directly or indirectly to sparking between the brushes and the commutator. The load on a railway motor is almost constantly varying, and this in turn affects the armature reaction and thus causes a variation in the distribution of the magnetic lines of the field. It is impractical to change the position of the brushes for every variation in load; therefore, since in most cases the motor armature must be able to rotate in either direction, the brushes are usually set at the theoretical neutral points—that is, midway between the poles—and because of this position, the brushes may not be in the best position for commutation at all times, especially when the motor is heavily overloaded.

Commutating poles are small pole pieces situated midway between the ordinary pole pieces on the frame of a generator or motor, and their use has resulted in producing practically sparkless commutation under varying load conditions and even when the motor is much overloaded. Commutating poles have been applied to generators and to shunt-wound motors, but are of particular advantage in the case of railway motors, on account of the severe variations in load to which motors of this type are subjected.

26. In Fig. 19 (*a*) are shown the four pole pieces of an ordinary railway motor. The brushes *a* are shown situated midway between the pole pieces. In a railway motor, the field coils and the armature are connected in series, so that when the fields are unshunted, as is usually the case, and when the motor is running, the same number of amperes of

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current flows through the field coils and through the armature. Curve *b*, however, represents approximately the distribution of the magnetic lines of the field poles, assuming

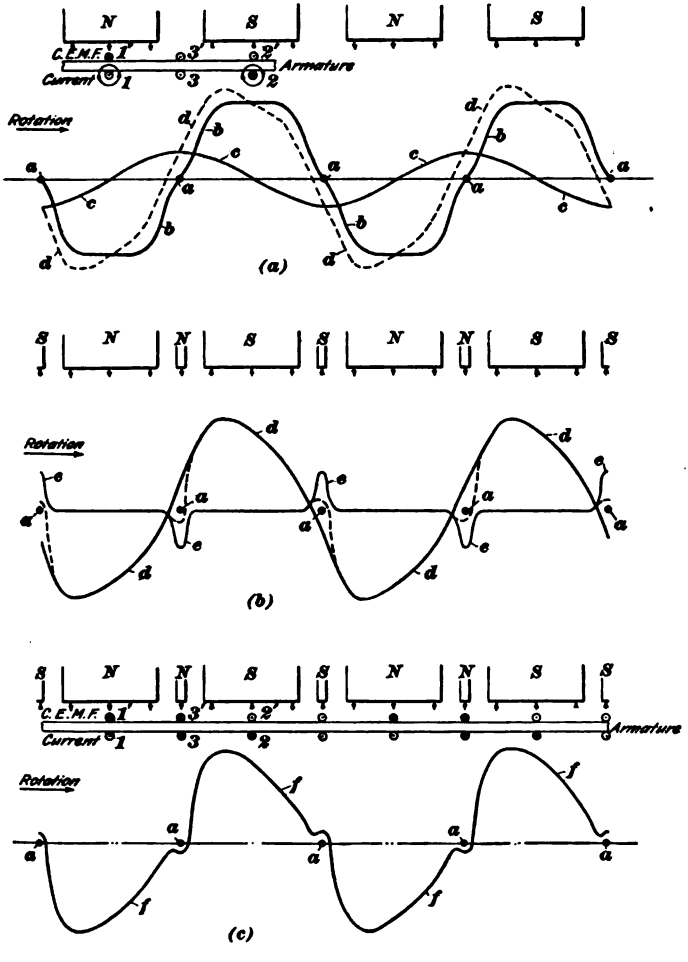

FIG. 19

that normal current is flowing through the field coils and that no current is flowing in the armature. The portions of curve *b* below the brush line *a a* indicate the distribution and

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the comparative density of the magnetic lines emanating from the north-pole pieces, while the portions of the curve above the brush line indicate the distribution and the comparative density of the magnetic lines entering the south-pole pieces.

When current flows through the armature, other sets of magnetic lines are produced, and the distribution and comparative density of these lines, considering the effect of armature current only, are indicated approximately by curve *c*. The direction of rotation is assumed to be as indicated by the long arrow; therefore, as explained in *Electric Motors*, the direction of current in a conductor at position *1*, under the north pole, is upwards, or toward the front of the armature, while the current in a conductor at position *2*, under the south pole, is downwards. The magnetizing effect of the armature current is a maximum midway between the poles, and the direction of the magnetic flux set up by the armature current is opposite to the direction of the lines emanating from the right-hand side of the north-pole piece and in the same direction as the lines entering the left-hand side of the south-pole piece, as shown by a comparison of curves *b* and *c*. It should be noted that the conductors at positions *1* and *2* tend to send magnetic lines toward the top surface of the armature core in the space between these conductors. The curve *c* thus represents the magnetic flux due to the armature current only.

The resultant magnetic flux produced by the motor current flowing through the field coils and the armature is indicated approximately by curve *d*, which is formed by combining the values indicated by the two component curves *b* and *c*. The distortion of the resultant magnetic flux is clearly shown by curve *d*. The density of the magnetic field is comparatively high at the pole tips toward which the armature is moving, and low at the pole tips from which the armature is receding.

27. The neutral spaces, where the resultant flux is zero, have been shifted backwards, so that the armature conductors connected to the commutator bars on which the brushes rest

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are cutting across a south magnetic field. The coils short-circuited by the brushes thus have an electromotive force generated in them. The direction of the motor current in an armature conductor at position *1* is upwards, as indicated, but the counter electromotive force in the same conductor is downwards, as indicated at *1'*. When the conductor is at position *3*, directly over the brush, the direction of the resultant flux is opposite to its direction at position *1*. Therefore, the direction of the electromotive force generated in the conductor at position *3'* is opposite to the direction of the counter electromotive force generated in the conductor when at position *1'*.

Since the conductor at position *3* is part of a coil short-circuited by the brush, the direction of current flow in the conductor and coil is determined by the direction of the electromotive force generated in the coil at the point of commutation. Both the electromotive force and the current flow are upwards in the conductor at position *3*. When the coil moves out from contact with the brush, the motor current in the coil or conductor will at once flow in a direction opposite to the direction of the flow of current in the group of conductors to which it was joined before commutation, and also in a direction opposite to the direction of flow of current during commutation. The motor current in the conductor will now flow in the same direction as the current flowing in the group of conductors to which it is now joined in series. The new direction is downwards, as indicated at position *2*. The sudden reversal of current in the coil as it passes out from under the brush causes a high electromotive force of self-induction to be set up in the coil, and this, when the coil comes out from under the short circuit and is joined to the coils ahead of it, causes a spark to jump between the brush and the departing commutator bar as the bar leaves contact with the brush.

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ACTION OF THE COMMUTATING POLES

28. In Fig. 19 (*b*), the small commutating poles are shown in their proper relative positions between the main pole pieces. The windings of the coils on the commutating poles are connected in series with the windings of the main field coils and the armature. The polarity of the commutating poles is as indicated, and the magnetic strengths of the poles are so proportioned that the magnetic field of the commutating poles more than overcomes the magnetic field due to the armature current at the points directly under the commutating poles.

Curve *d*, Fig. 19 (*b*), is similar to curve *d*, Fig. 19 (*a*). Curve *e*, Fig. 19 (*b*), indicates approximately the distribution and the comparative density of the magnetic field due to the commutating poles. The resultant magnetic flux of the components *d* and *e* is shown by curve *d* corrected by the dotted lines near the brush positions or more clearly by curve *f*, Fig. 19 (*c*). Curve *f* represents the true magnetic flux of the commutating-pole motor, and is the resultant of component curves *b*, *c*, and *e*.

29. The conditions regarding counter electromotive force and current at positions *1* and *2*, Fig. 19 (*c*), are similar to those in the same positions in (*a*). The conditions at position *3*, in (*c*), are the reverse of the conditions at position *3*, in (*a*). The conductor at position *3'*, in (*c*), has an electromotive force generated in it in the same direction as the counter electromotive force generated in the conductor at position *1'*, since in both positions the conductor is cutting lines emanating from north poles. The direction of the current in the conductor at position *3*, owing to the electromotive force generated in the coil under commutation, is downwards, and the direction of the current in the conductors to which it is to be connected is also downwards. The current is thus reversed in the coil during commutation, and before the coil leaves connection with the brush the current in it is in the same direction as the current in the coils to which it is to be joined; thus, there will be little

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change of current in the coil as it leaves the brush, and therefore little tendency to spark at the brush.

30. Since the armature, the commutating-pole coils, and the main field coils are in series, as shown in Fig. 20, a variation in motor current produces variations in both the armature reaction and the opposing strength of the commutating poles, so that by proportioning the parts properly, commutation can be made practically sparkless for all loads. Since the armature and the coils on the commutating poles are connected together permanently, and the field coils and the armature circuit are connected together through the reversing device, the polarity of the commutating coils will be reversed if the direction of current flow through the armature circuit is reversed; and if the current through the main field coils is reversed, the polarity of the main field poles is changed, but the polarity of the commutating poles remains unchanged. In either case, the relative polarities of the main poles and the commutating poles are correct for the reversed direction of rotation of the armature.

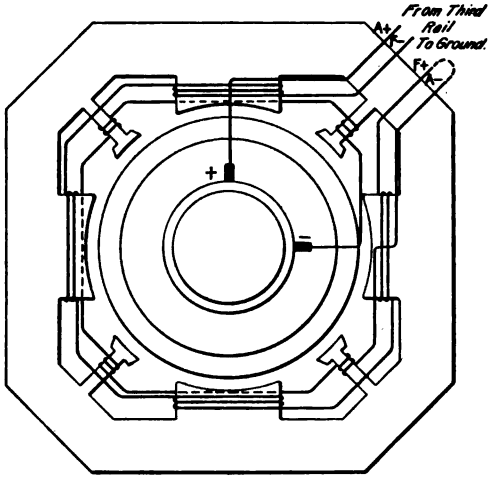

FIG. 20

TYPES OF COMMUTATING-POLE MOTORS

GE-209 MOTOR

31. In Fig. 21 is shown a **GE-209 commutating-pole, 300-horsepower motor** of the box-frame type with the armature and one frame head removed, thus

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exposing the windings of the main field poles and the commutating poles.

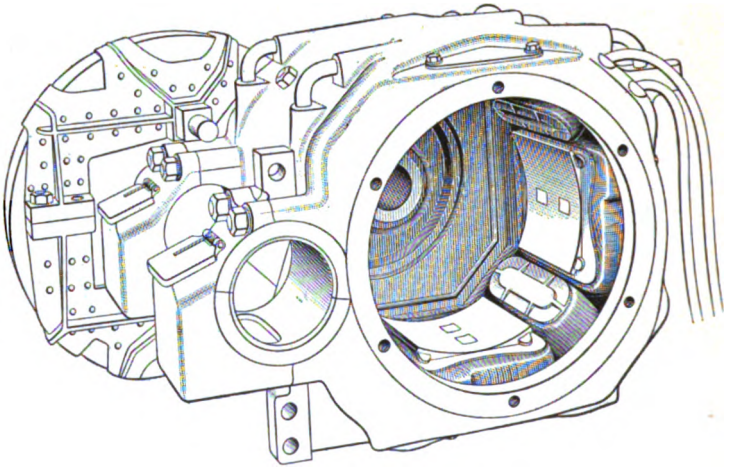

FIG. 21

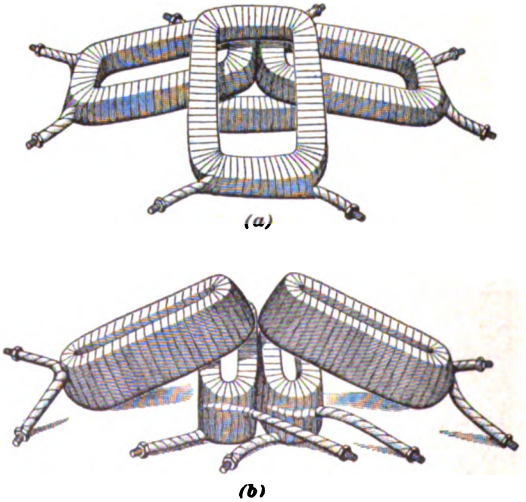

FIG. 22

The main field coils for motors of this type are shown in Fig. 22 (*a*), and the commutating field coils in (*b*).

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WESTINGHOUSE 300 MOTOR

32. In Fig. 23 is shown a **Westinghouse 300 motor** of the commutating-pole type. The nominal rating of this motor is 200 horsepower. The main field-pole bolts are shown at *a*, and the commutating field-pole bolts at *b*. The

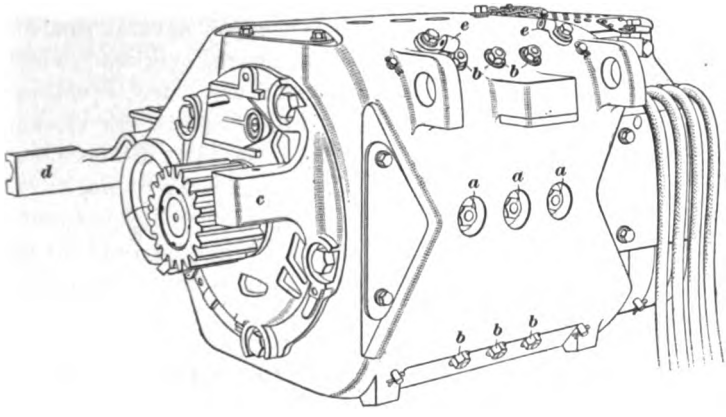

FIG. 23

gear-case is supported by lugs *c* and *d*. The ground wires of the car-wiring system are connected to terminals *e*, which are bolted to the motor frame.

ALTERNATING-CURRENT MOTORS

33. If a high-voltage alternating current is supplied to the trolley line and then utilized for propelling cars by means of alternating-current motors, the trolley wire may be of moderate size, even though its length is great and the car load heavy. With alternating current in the transmission lines from the main stations to the substations and in the trolley lines, the substations need contain only static transformers and auxiliary switching apparatus; that is, no moving machinery is necessary. The substation equipment is then of comparatively low cost, and little, if any, attendance, except regular inspection, is required.

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The development of such a system was long delayed by the lack of a suitable single-phase, alternating-current motor. However, successful single-phase, series-wound commutator motors, which may be efficiently used on either alternating- or direct-current lines, as well as other apparatus necessary to make up a complete alternating-current railway system have been developed.

Polyphase induction motors are used on several roads in Europe. This necessitates two or more overhead wires. In a three-phase system, two overhead wires are sometimes used, with the rails acting as the third side of the system. Besides the complication of the overhead work, the induction motor is not well fitted for variable-speed railway work.

As the development of alternating-current railway work in the United States has been mostly along the lines of the single-phase system, motors applicable to this system will be described.

REVERSAL OF CURRENT

34. When an alternating current flows through the field winding and armature winding of a series motor, the polarity

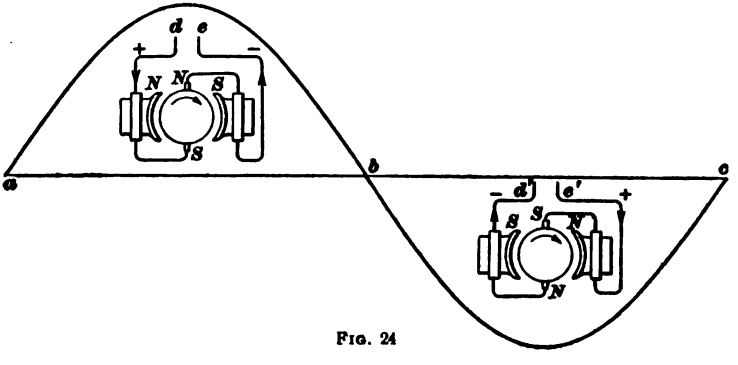

FIG. 24

of the field pole pieces and the direction of the current in the armature conductors change at practically the same instant. Continuous rotation in a given direction is therefore maintained. In Fig. 24, curve *a b c* represents one cycle of an alternating current. In the portion of the cycle *a b*, the

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current is assumed to flow from motor lead *d* to lead *e*, resulting in the polarity and rotation shown. At *b*, the direction of flow of current is reversed; it now flows from lead *e'* to lead *d'*, thus reversing the polarity of field poles and armature poles, but not the direction of rotation, which remains unchanged, as indicated.

In the case of an alternating-current motor, as well as of a direct-current motor, the direction of rotation is not reversed where *both* the field terminals and the armature terminals are reversed, but the rotation is reversed when *either* the field terminals *or else* the armature terminals are reversed.

The frame on which the field coils of the alternating-current motor are mounted, as well as the armature core, is laminated in order to prevent eddy currents, which otherwise would be set up by the alternating current in the motor windings.

SELF-INDUCTION

35. Field.—An electromotive force of self-induction is set up in the windings by the alternating current flowing through them. In the case of the main field windings, this electromotive force is reduced to its lowest value by reducing the turns of the exciting field coils to the least number capable of providing the necessary magnetic flux. The less the number of turns that are acted on by the alternating magnetic flux passing through them, the smaller becomes the electromotive force of self-induction.

36. Compensating Field and Armature.—The self-induction of the armature winding is practically suppressed by the action of a *compensating field winding*. This winding is frequently called an *auxiliary winding* or a *neutralizing winding*, and these terms will be used interchangeably in the following discussion. The main field winding, the armature, and the compensating winding are connected in series.

In Fig. 25 is shown the development of a portion of the windings of a compensated, single-phase, alternating-current series motor. The direction of motion of the armature core

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is indicated by the large horizontal arrow. Only one armature coil with its corresponding compensating coil is shown. In the actual motor, there are numerous armature coils and compensating coils, the armature coils being placed in slots in the armature core, and the compensating coils, having much the same distribution, in slots in the pole faces. Two pole pieces and two main field coils are shown, as well as the resulting polarity of the poles when the current is flowing through the field coils in the direction indicated by the arrowheads.

In order to obtain rotation in a given direction, there must be a certain relation between the polarity of the pole pieces and the direction of current flow in the armature conductors

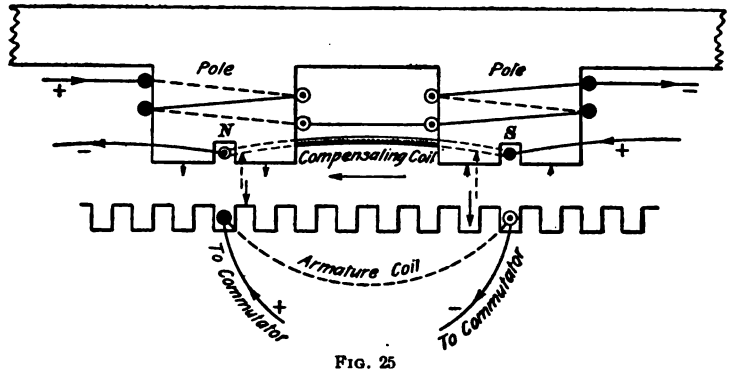

FIG. 25

under the poles. With the polarity as shown, and the direction of rotation as indicated by the horizontal arrow, the current in the armature coil flows in a counter-clockwise direction when viewed from the lower portion of the figure. The current is an alternating one, so that, while the coil is passing from contact with one brush to contact with the next, the current through the motor windings may reverse once or more. At the instant under consideration, the current in the armature coil tends to set up a magnetic flux in the direction indicated by the full-line vertical arrows. The compensating coil is so connected that the current flowing through it has a tendency to set up a magnetic flux in the direction indicated by the vertical dotted arrows. These two magnetic fluxes

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oppose each other. If the current reverses, both magnetic fluxes are reversed in direction, and therefore still oppose each other. These fluxes practically neutralize each other in their action on the sets of coils. The self-induction in one winding is nearly neutralized by mutual induction from the other winding.

37. When a current flowing through a coil changes in value, the number of lines of force embraced by the coil also changes, and this change in the number of lines sets up an

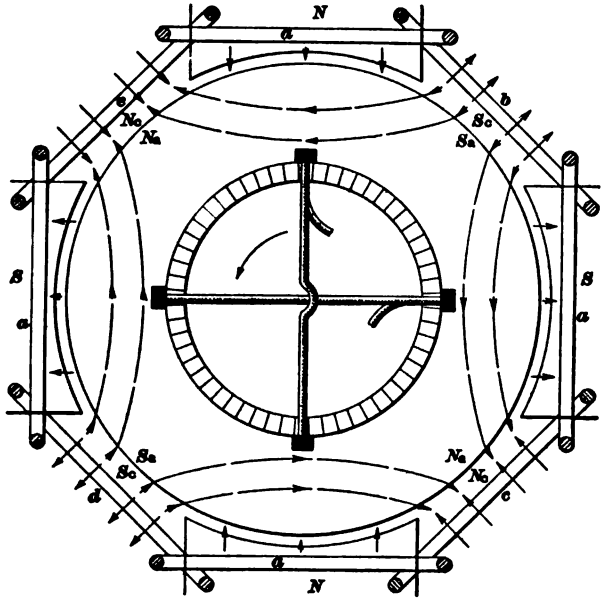

FIG. 26

electromotive force of self-induction in the coil. If means are provided so that the first coil is subjected to the effects of induction from a second coil having an opposing magnetic flux, the coil will be practically free from self-induction, and the same value of either direct or alternating electromotive force will send about the same current through the coil. This is the effect of the action of the compensating coils on the armature coils, and that of the armature coils on the com-

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pensating coils. In addition to reducing the self-induction of the armature coils and compensating coils, and thereby improving the power factor of the motor, the current in the compensating winding so neutralizes the armature reaction that proper commutating conditions may be secured with fewer turns on the field winding, and thus a weaker field, than would otherwise be possible.

38. Relative Arrangement of Coils.—In Fig. 26 is shown the relative arrangement of armature, pole pieces, main field coils, and compensating coils for a four-pole motor. The main field coils are shown at *a*, and the compensating field winding at *b*, *c*, *d*, and *e*. The armature, if of large size, is usually parallel wound and arranged for a four-pole field.

It is assumed that at a given instant the alternating current is flowing in such a direction through the main field coils, the armature, and the compensating coils as to tend to make the top and bottom pole pieces north poles and the side pole pieces south poles; to make two north poles N_a and two south poles S_a at the points indicated on the armature core; and to make the inner sides of compensating coils *c* and *e* north poles N_c, and the inner sides of compensating coils *b* and *d* south poles S_c. The directions of these sets of lines of force are indicated by short arrows and arrowheads. When the current reverses, the polarities at all of these points are also reversed. As the compensating winding—here shown as four coils—in practice is distributed over the pole faces and is so connected that the current in the turns of the coils tends to set up in the pole faces and between the pole tips lines of force that directly oppose the lines of force caused by the current in the adjacent armature coils, the self-induction of the compensating winding and the armature winding is nearly, but not entirely, neutralized.

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ARMATURE TRANSFORMER ACTION

39. When the armature is rotating in the magnetic field set up by the main field coils, a counter electromotive force is generated in the armature coils in the same manner as in a direct-current armature. There is also set up in the

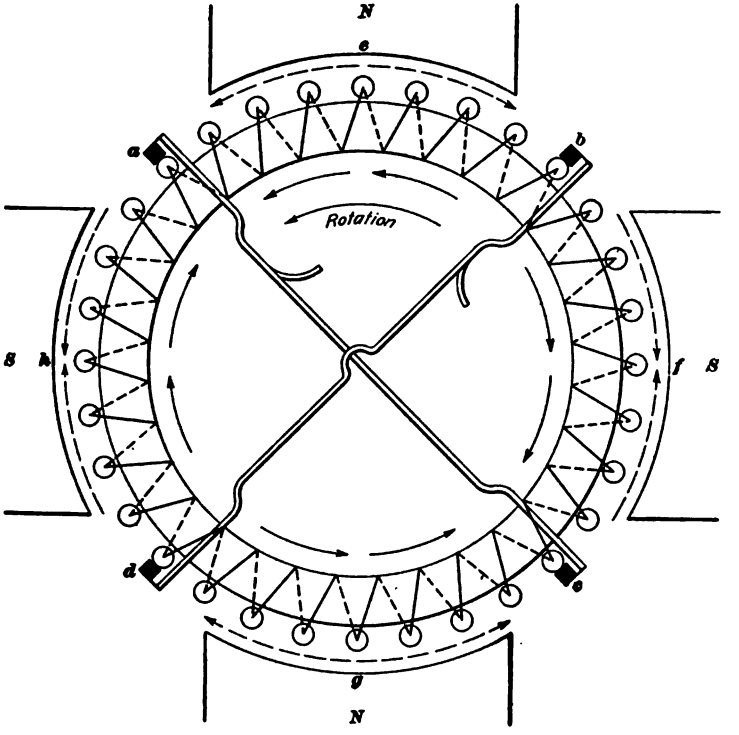

FIG. 27

armature coils an electromotive force due to the alternating magnetic flux passing through the pole pieces and armature. This is practically a transformer action. The first, or mechanically generated, electromotive force is proportional to the speed; the second, or electrically generated, electromotive force is proportional to the frequency of the alternating current. The first electromotive force is the useful

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one, as it is the counter electromotive force of the motor. The effect of the second electromotive force in part of the coils is neutralized by the effect of the same force in the remaining coils, as illustrated in Figs. 27 and 28, so that the second electromotive force does not affect the first.

40. Ring Winding.—In Fig. 27, the polarity of the pole pieces at a given instant and the direction of rotation of the armature are assumed to be such that the counter electromotive forces generated are in the directions indicated by the full-line arrows. The directions of the counter electromotive forces are away from brushes *b* and *d* and toward brushes *a* and *c*. For convenience in representation, a ring-wound armature is shown; all the coils, which are indicated by spirals, are wound and connected in a similar manner.

41. The direction in which an induced current circulates around a coil depends on the direction of the lines of force in the coil and whether their number is increasing or diminishing, and may be determined by the following rule:

Rule.—*If the effect of the magnetic action is to diminish the number of lines of force that pass through the coil, the current will circulate around the coil in a clockwise direction, as viewed by a person looking along the magnetic field in the direction of the lines of force; but if the effect is to increase the number of lines of force that pass through the coil, the current will circulate around the coil in a counter-clockwise direction, as viewed by a person looking along the magnetic field in the direction of the lines of force.*

The alternating magnetic flux at a given instant is supposed to be increasing in value, and is of the polarity indicated by the letters on the pole pieces. Standing at point *e*, Fig. 27, and looking along the lines of force toward *h*, the increasing magnetic flux will set up an electromotive force that will tend to send a current around the turns of wire in a counter-clockwise direction; that is, the electrically generated electromotive force is from *e* to *h*. By similar reasoning, the electrically generated electromotive forces are found to be

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from *e* to *f*, from *g* to *h*, and from *g* to *f*, as indicated by the long dotted arrows. In the set of coils between any two brushes, it should be noted that the electrically generated electromotive force in half of the coils is directly opposed by the electrically generated electromotive force in the other half of the same set of coils. These electromotive forces therefore neutralize each other, and the counter electromotive

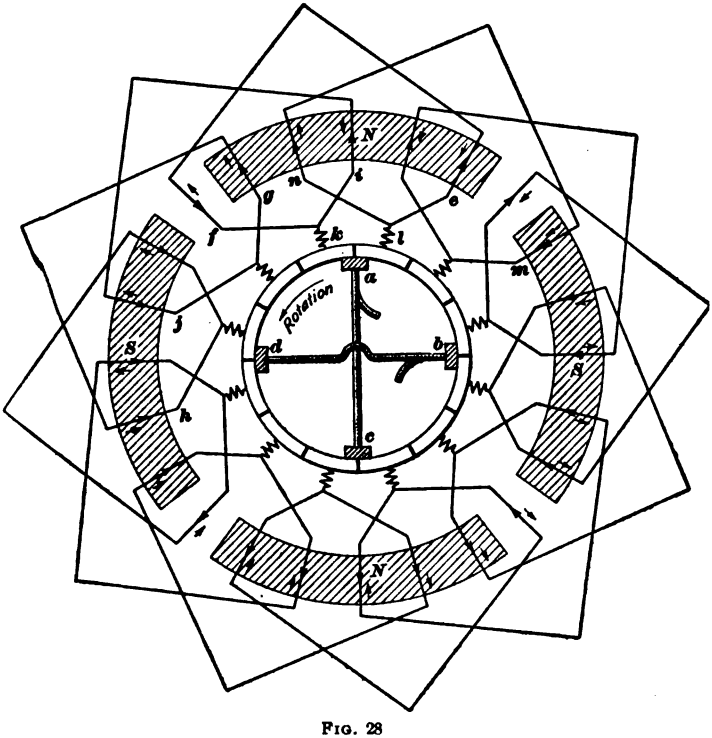

FIG. 28

force is affected very little, if any, provided the brushes are on the neutral points.

42. Drum Winding.—In Fig. 28 is shown a developed winding of a parallel-wound, four-pole drum armature. The field magnetic flux is assumed to be increasing in value and of the polarity shown. The directions of the counter electromotive forces are indicated by the arrowheads on the con-

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ductors. Lines of force are coming up through coil *e f* from the north pole below it. The electrically generated electromotive force, which is the result of transformer action, is in such a direction as to tend to send a current around the coil that, if it actually flowed, would set up lines of force opposite in direction to those emanating from the pole piece. The flow of current in coil *e f* would thus be clockwise, and the direction of the lines of force would be downwards through the coil. The directions of the electrically generated electromotive forces in the coils are indicated by the short arrows near the conductors.

Where a coil embraces parts of both a north pole and a south pole, the pole having the larger portion under the coil is assumed to exert the preponderant influence. For instance, coil *g h* lies partly over a north pole, but mostly over a south pole. Lines of force are increasing in value and are passing down through the coil into the south pole. The electrically generated electromotive force is in a counter-clockwise direction, and tends to set up a current that will in turn set up lines of force passing up through the coil, these lines being opposite in direction to the main field lines passing into the south pole. It should be noted that in coils *i j* and *g h*, which are connected between brush *a* and brush *d*, the counter electromotive force is in a counter-clockwise direction in both coils, but that in coil *i j* the electrically generated electromotive force is clockwise, while in coil *g h* it is counter-clockwise. The electrically generated electromotive forces thus neutralize each other so far as their effect on the counter electromotive force is concerned. The same conditions hold true for the other quarters of the winding.

43. Commutated Coil.—A point of importance is the effect of the alternating magnetic flux on the coils short-circuited by the brushes. In the position shown in Fig. 28, coil *e f* has its ends connected by brush *a*. The coil is over the pole piece *N*, and as the polarity of the pole piece is periodically changing, an alternating magnetic flux is set up in the coil as it moves past the pole. The coil acts as a

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closed secondary of a transformer, of which the field winding on the pole piece N is the primary. The ohmic resistance of the closed circuit is low, and a very large current would flow through the coil and thus cause violent sparking at the brushes when the local circuit is broken if precaution were not taken to prevent it. In order to reduce the short-circuited current, usually only one turn per coil is used, a low frequency of the alternating current is employed, a low value of electromotive force is applied to the motor terminals, and the magnetic circuits are carefully designed.

A method of still further reducing the short-circuited current is to connect the junctions of the coils to the commutator bars with leads of resistance metal, as shown at k, l. The resistance of these leads prevents an excessive current from flowing through the local circuit composed of the coil $e f$, the leads k, l, the two commutator bars, and the brush a. The leads carry current only when the commutator bars to which they are connected are in contact with the brushes, as the armature windings form a closed circuit independent of the leads.

The loss occasioned by the resistance of the few leads in circuit at the brushes at any time is slight. In small alternating-current armatures, such as are used in motors for driving air compressors, no resistance leads need be used, as the brushes usually have sufficient resistance to limit the short-circuited current. In railway motors of ordinary size, the resistance leads are usually tapped to the armature winding at the rear end of the core and brought to the commutator bars through the same slots as the main winding. In some of the large locomotive motor armatures, in order to secure a greater length, the leads are tapped to the armature winding at the front end of the core, carried to the rear end, doubled back to the front end, and then connected to the commutator. In case a short circuit should occur in the field windings or in the armature, the alternating magnetic flux would cause an excessive current to flow through the short-circuited section and perhaps cause a burn-out.

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VOLTAGE RELATIONS

44. The main field coil acts as a choke coil, and has generated in it a counter electromotive force of self-induction. This introduces into the alternating-current motor a voltage that is not present in the direct-current motor and that increases the total voltage required to run the motor. As the field coil, armature, and compensating coil are in series, the voltages across the several sections of the winding may be considered as making different phase angles with the current flowing in series through the whole winding. In such a case, the total voltage would not be the numerical sum of the several voltages, as the difference in phase relation must be considered.

The total voltage may be determined by the aid of a diagram similar to Fig. 29. When two forces acting in different directions are represented by the lengths and directions of two connecting lines—the force in one line acting from its free end toward the junction of the two lines, and the force in the other line acting from the junction toward its free end—the value and the direction of the resultant force are indicated by the length and the direction of the line connecting the free ends of the two lines, the direction of the resultant force being taken as opposing the general direction of the two forces around the triangle of forces. If the direction of the two forces around the triangle is clockwise, the direction of the resultant force is counter-clockwise.

In Fig. 29 (*a*) is shown the motor circuit, and in (*b*), the voltage diagram. The sketches are so lettered that line *a b* in (*b*) represents the voltage across the field coil *a b* in (*a*); line *b c* in (*b*), the voltage, under running conditions, across the armature and compensating coil *b c* in (*a*); and line *a c*, the resultant, in (*b*), the total voltage across the motor terminals *a c* in (*a*).

45. The directions of the current and voltages are indicated by arrowheads. The value of the current *a d*, Fig. 29 (*b*), is laid off on the horizontal line through *a*. As

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the field coil has self-induction, the field-coil voltage $a\,b$ is the resultant of two components—one component $a\,f$ necessary to overcome the counter electromotive force of self-induction of the coil, this voltage being 90° out of phase from the current, and the other $f\,b$, or $a\,e$, necessary to force the current against the ohmic resistance of the coil and to make up for other electrical losses, this voltage being in phase with the current. It should be noted that $f\,b$ is short in comparison with $a\,f$; therefore, the angle of lag g between the resultant electromotive force $a\,b$, applied to the field coil, and the current will be nearly 90°.

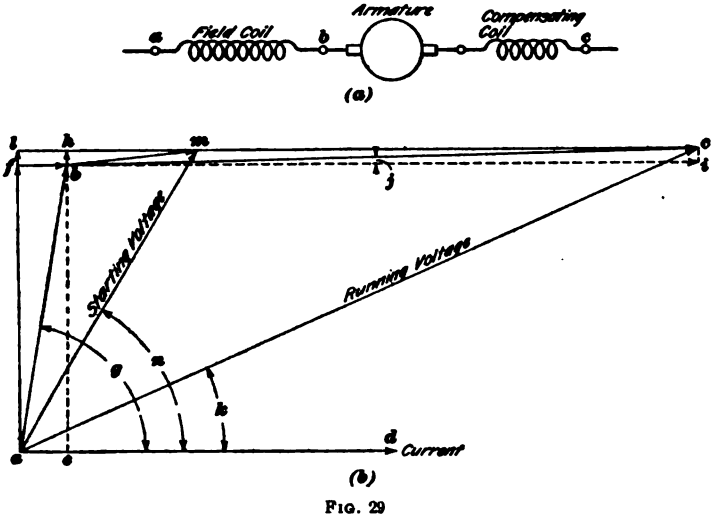

FIG. 29

There is little self-induction in the combined armature and compensating coil, while the energy component, under running conditions, of the applied voltage is large, since it represents, in addition to the loss in the armature and the compensating coil, due to the current flowing against their ohmic resistances, other electrical losses and the electrical energy transformed into mechanical work. The component of the applied voltage on $b\,c$, Fig. 29 (a), necessary to overcome self-induction is represented by the vertical line $b\,h$, Fig. 29 (b), erected at the end b of field-voltage line $a\,b$.

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The energy component is represented by hc, or bi, which is in phase with the current. The resultant, which represents the voltage applied to the combined armature and compensating coil, is bc, and since the energy component is much the larger, the applied voltage will be nearly in phase with the current, as shown by the small angle of lag j. The direction of the current is indicated by the line bi parallel to ad.

The resultant of ab and bc, which is the running voltage ac, is found by drawing a line from a to c, these points being at the free ends of the lines representing the electromotive forces applied to ab and to bc, Fig. 29 (a). The direction of this voltage is from a to c, Fig. 29 (b), as indicated by the arrowhead. Considering the triangles of forces abc, the general direction of the arrowheads on sides ab and bc is clockwise, while the arrowhead on ac indicates a counter-clockwise direction. The angle of lag between the running voltage and the current is angle k. The running voltage is also the resultant of the total inductive component $al = af + bh$ and the total energy component $lc = fb + hc$.

46. Suppose the motor to be starting and the terminal electromotive force to be reduced so that the current through the motor windings is the same as the running current. Since the current is the same, the lines representing the electromotive forces necessary to overcome the ohmic resistance and other losses of the field coil, to overcome the counter electromotive force of self-induction in the field coil, and to overcome the counter electromotive force of self-induction in the combined armature and compensating coil, may remain practically unchanged. These lines are fb, af, and bh, Fig. 29 (b). The energy component of the combined armature and compensating coil is now small, since the developed power at starting is inconsiderable. This component is made up of the voltage necessary to force the current through the ohmic resistance of the armature and compensating coil and to make up for the other electrical losses in these parts. At h, lay off hm equal to this energy

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component; the resultant $b\,m$ represents the voltage across $b\,c$, Fig. 29 (a), under starting conditions. The line $a\,b$, Fig. 29 (b), remains unchanged, as the current value is assumed to be the same as under running conditions. The starting voltage $a\,m$ is the resultant of $a\,b$ and $b\,m$, and represents approximately the electromotive force applied to the motor terminals when starting.

The angle of lag k between the running voltage and the current is much smaller than the angle of lag n between the starting voltage and the current. Therefore, the current in the first case is more nearly in phase with the electromotive force, and the power factor under running conditions is much higher than under starting conditions.

If the self-induction of the armature had not been neutralized by the action of the compensating coil, the power factor would have been lower under both starting and running conditions. At starting, the counter electromotive force of self-induction of the field coil has a much greater effect on the total motor voltage than under running conditions, owing to the inductive component not changing greatly, while a great change takes place in the energy component. With alternating current, the starting voltage is a larger proportion of the final running voltage than when direct current is used on the same motor and under similar conditions.

47. The laminated field, the compensating winding, and the low voltage between commutator bars, which are necessary for operation on alternating current, make the performance of the motor on direct current excellent. Owing to the lack of inductive elements and to the elimination of certain alternating-current losses, this type of motor will produce the same speed and output at a slightly lower voltage when operating with direct-current supply than when operating with alternating-current supply.

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TYPES OF ALTERNATING-CURRENT MOTORS

WESTINGHOUSE 132 MOTOR

48. Description of Motor.—In Fig. 30 is shown the exterior of a **Westinghouse type 132 motor.** This is a single-phase, alternating-current railway motor having a nominal rating of 100 horsepower. The laminated core on which the field windings are placed is built into the cast-steel outer frame that holds the core in position. The end brackets are fitted on machined seats and support the armature bearings. The frame is of the box type. The armature may be removed by taking off either the pinion-end bracket or the commutator-end bracket and the pinion. To give access to the brushes and brush holders, openings are provided in the frame, both above and below the commutator.

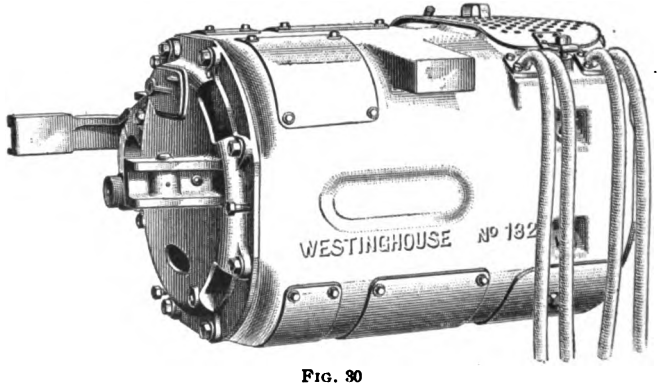

FIG. 30

The laminated field core is so constructed as to form four projecting pole pieces, on which the four main field coils are placed. The faces of these pole pieces contain slots, in which are placed the conductors constituting the compensating field winding, as shown in Fig. 31. The main field coils consist of a few turns of heavy copper strap, and are mounted on the short, projecting pole pieces. The compensating, or neutralizing, coils, consisting of copper bars

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connected at the ends by copper straps so as to form a continuous winding, are distributed in a number of slots in the

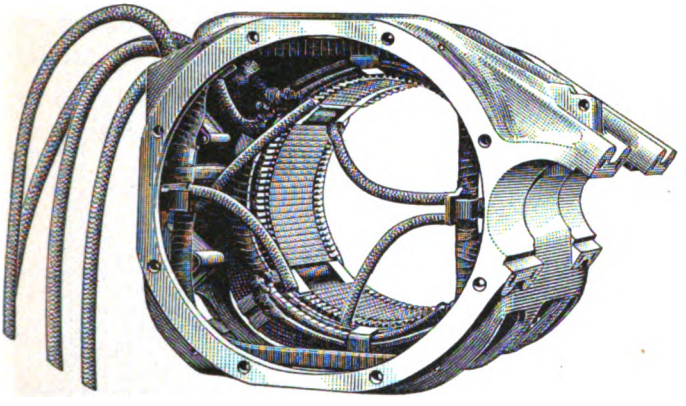

FIG. 31

pole pieces, in order to obtain a distribution similar to that of the armature conductors.

The action of the current in the conductors of the compensating coils neutralizes the self-induction of the adjacent armature conductors. As there is mutual induction between

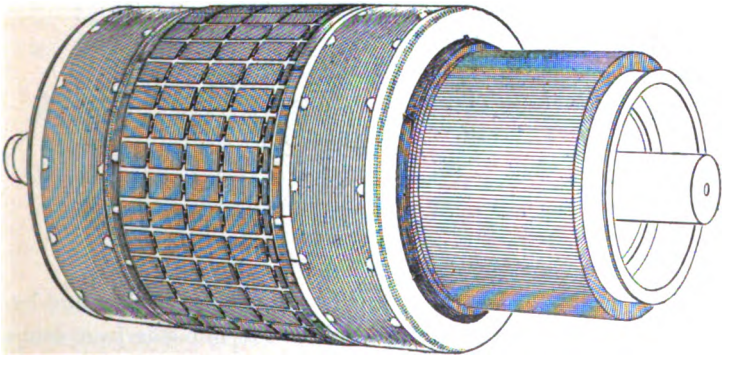

FIG. 32

the compensating winding and the armature winding, the self-induction of the compensating coils is also reduced.

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The main field winding is thus the source of most of the electromotive force of self-induction of the motor winding.

Fig. 32 shows the armature for the type 132 motor. Resistance leads are used to connect the back end of the armature coils to the commutator bars, and thus prevent an

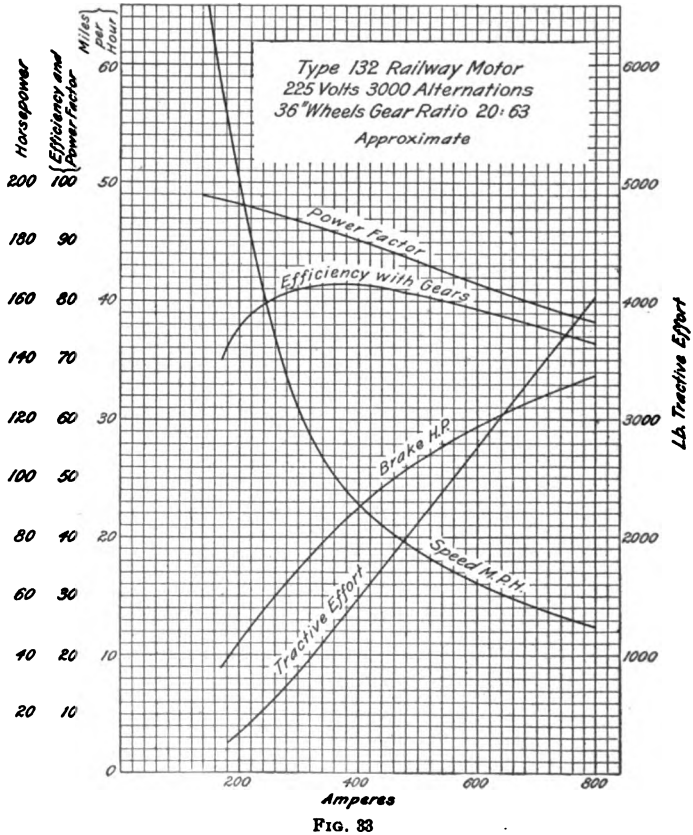

FIG. 33

excessive current from flowing in the coil short-circuited by a brush. The armature is parallel wound and has four sets of brushes. The main field coils, the armature, and the compensating field coils are connected in series. The motors are ordinarily wound for a potential of 250 volts. The frequency of the alternating current is usually 25 cycles.

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49. Performance Curves.—In Fig. 33 is shown a performance curve for a type 132 Westinghouse motor operating on 225 volts, single-phase alternating current. Fig. 34 shows a performance curve for the same type of motor

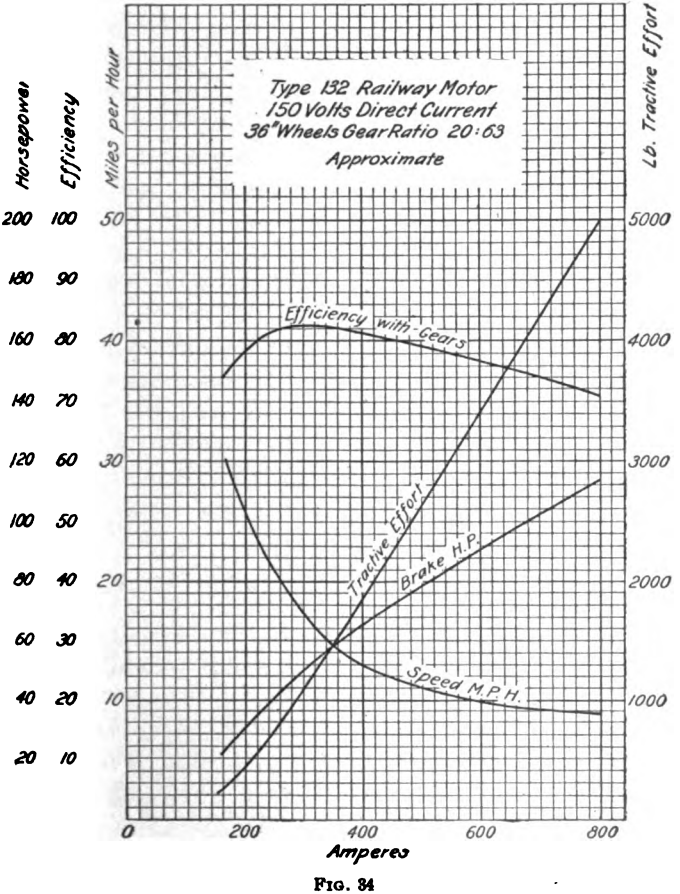

FIG. 34

operating on 150 volts, direct current. Four motors are in series on a 600-volt, direct-current circuit, and the speed is comparatively low, being suitable for city traffic. In order to use curves of this kind, proceed as follows: It is desired to find the tractive effort, Fig. 33, when the motor is taking

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a current of 460 amperes. Each small space on the base line *0–800* represents 20 amperes; therefore, the 460-ampere line is 460 ÷ 20 = 23 lines from the point *0*, or 3 lines to the right of the point *400*. The 460-ampere line cuts the tractive-effort curve at a point about 18½ spaces above the base line. As each space equals 100 pounds of tractive effort, as shown by the line of values on the right-hand margin, 18½ spaces equal 1,850 pounds. With the same current flow, the speed in miles per hour is 20, as shown by the line of values of miles per hour. The brake horsepower is 100; the efficiency with gears, nearly 82 per cent.; and the power factor, .88.

By selecting a certain point on one curve, corresponding values on the other curves may be found by determining the place where a vertical line through the selected point cuts the other curves and then reading the values of these points by means of the data lines on the margins. For example, in Fig. 33, the point of highest efficiency is on the 360-ampere line; under these conditions the horsepower is nearly 82, and the tractive effort about 1,200 pounds.

GEA-605-A MOTOR

50. Description of Motor.—In Fig. 35 is shown a type of single-phase, alternating-current motor manufactured by the General Electric Company, and known as the **GEA-605-A motor.** This motor is rated at 75 horsepower, and may be operated on either alternating- or direct-current railway systems. The core on which the field windings are placed is laminated, and is held in position by the outer steel casting forming the structural frame of the motor. The housing and the inner laminated ring of the motor are shown in Fig. 36. The field windings are in two sections, namely, the exciting winding mounted on short poles formed in the laminated core and the compensating winding placed in slots in the pole faces. The field windings and the armature are connected in series.

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The armature has a series-drum winding similar to a direct-current winding, but as the current taken by the

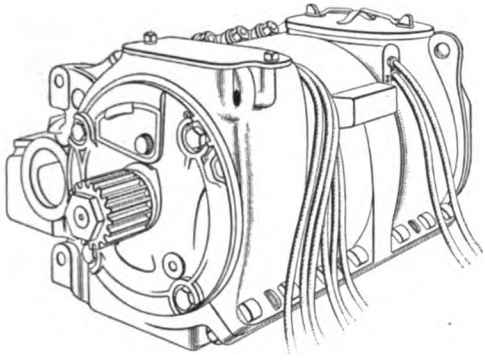

FIG. 35

motor is large, four sets of brush holders, each set containing four brushes, are provided. The motors are designed

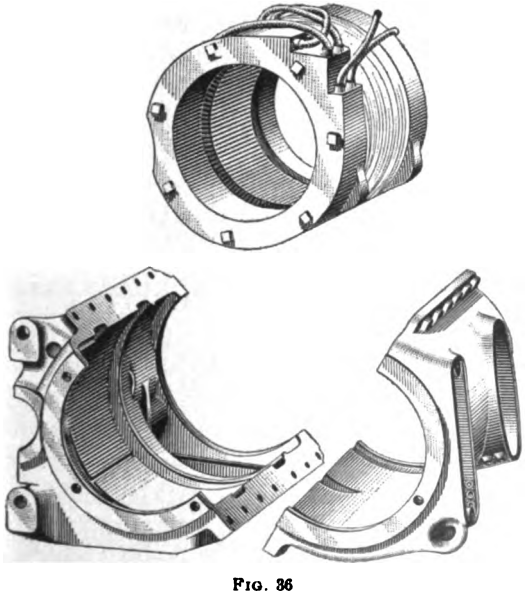

FIG. 36

for an electromotive force across their terminals of about 250 volts.

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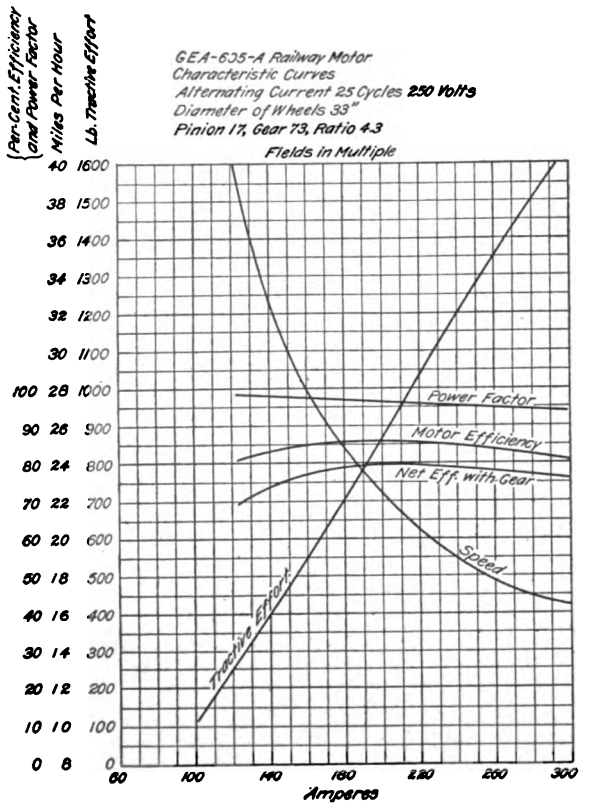

FIG. 87

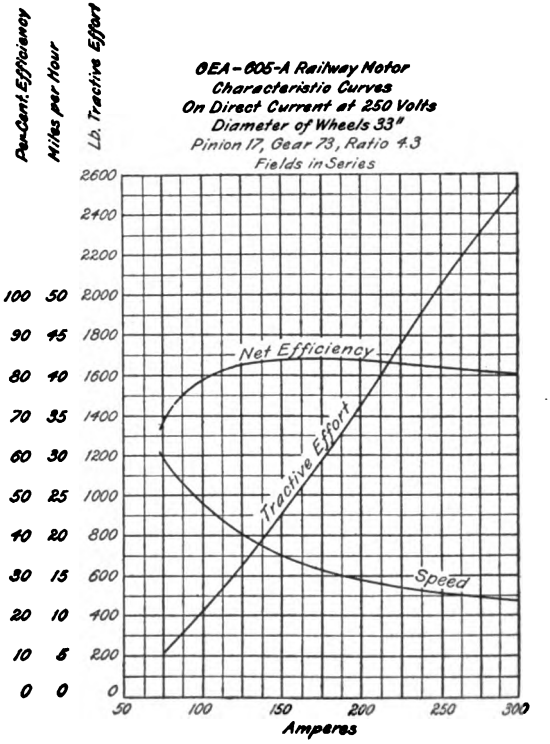

FIG. 88

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51. Performance Curves.—In Fig. 37 is shown a performance curve of a GEA-605-A motor operating on 250 volts, alternating current. Fig. 38 shows the performance curve of the same type of motor operating on 250 volts, direct current. In these curves, the alternating-current voltage and the direct-current voltage are the same. When operating with alternating current, the highest net efficiency is 80 per cent., and when operating with direct current, 83.5 per cent.

MOTOR SUSPENSIONS

52. The term **motor suspension** applies to the manner of supporting the motor on the car axle and truck. The connection between the motor and axle must be firm, because irregular variations in the distance between them prevent the gears from meshing properly. As the armature and axle bearings are rigidly fixed to the motor frame, the distance between gear-centers cannot change, except in so far as wear in the bearings may change it. In making any change in gearing, the sum of the diameters of the gear and pinion must be kept the same; in other words, the sum of the circumference of the gear and pinion must be kept constant, otherwise the gear and pinion will not mesh properly. The condition of firm connection is thus fulfilled, whatever may be the method of suspension adopted.

LOCATION OF MOTORS

53. When a car has two axles and two motors are to be installed, or where there are four axles and four motors are to be installed, one motor is connected through its gears to each axle. The motors should be hung in the space between the axles when it is possible to do so. There are several reasons for this: When the car rounds a curve, the motor leads are less likely to cause trouble than when the motors are hung on the outside, as the leads are nearer the center of the truck. The amount of wire required for the motor

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TABLE II

PARTIAL LIST OF THE LARGER STANDARD RAILWAY MOTORS

General Electric			Westinghouse		
Trade Name	Current	Horsepower	Trade Name	Current	Horsepower
GE-80	Direct	40	101-B	Direct	40
GE-90	Direct	50	101-D	Direct	50
GE-87	Direct	60	101-H	Direct	50
GE-74	Direct	65	93-A	Direct	60
GE-73	Direct	75	112-B	Direct	75
GE-66	Direct	125	121-A	Direct	90
GE-76	Direct	160	119	Direct	125
GE-69	Direct	200	114	Direct	160
GE-202	Commutating-pole, direct	50	113	Direct	200
GE-213	Commutating-pole, direct	50	307		40
GE-215	Commutating-pole, direct	50	306		50
GE-216	Commutating-pole, direct	50	305		60
GE-204	Commutating-pole, direct	75	304	Commutating-pole,	75
GE-214	Commutating-pole, direct	75	303	550 volts, direct current	100
GE-205	Commutating-pole, direct	100	302		125
GE-206	Commutating-pole, direct	125	301		160
GE-207	Commutating-pole, direct	150	300		200
GE-208	Commutating-pole, direct	200	135-B	25-cycle, alternating	75
GE-212	Commutating-pole, direct	200	135-B	15-cycle, alternating	90
GE-209	Commutating-pole, direct	300	132	25-cycle, alternating	100
GEA-605-A	25-cycle, alternating	75	132-A	25-cycle, alternating	100
GEA-603	25-cycle, alternating	125	148	25-cycle, alternating	125
GEA-611	25-cycle, alternating	125	133	25-cycle, alternating	135
GEA-609	25-cycle, alternating	150			

Most of these motors are suitable for operation in connection with the multiple-unit control system.

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terminals is less. The motors being nearer the center of the truck, their weight acts with less leverage and does not subject the truck to so much stress as when hung on the outside; therefore, less stiffness, strength, and weight are required in the truck. When a car is started, stopped with a brake, or when the motors are reversed while the car is under headway, the pinions of the two motors tend to crawl around their respective gears in opposite directions. This action produces stresses in the truck rigging; and these stresses are greater when the motors are hung outside. These actions also affect the braking of the car.

When the number of axles is twice the number of motors to be installed—for example, when two motors are to be installed on a double-truck car—most mechanics prefer to suspend both motors on one truck, because only one truck need then be a heavy motor truck; the trail truck can be light, thereby decreasing the dead weight to be handled; the brake rigging is simplified; trap doors in the car floor are needed at only one end of the car; economy and simplicity in car wiring result.

TYPES OF SUSPENSION

54. Nose Suspension.—Fig. 39 shows a **nose suspension,** so called because one end of the motor *a* is suspended by means of a lug, or nose. The other end of the motor is suspended on the axle of car wheels *b*. The two springs *c*, *c'* are called, respectively, the **upper** and the **lower suspension spring.** These springs are supported on *d*, which is a steel bar extending across the truck and called a **suspension bar.** Whenever the motor frame rises or falls, it compresses one of these springs, which relieves the truck of any direct shock.

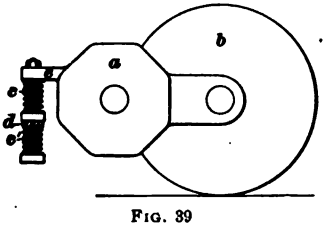

FIG. 39

All the corresponding letters in Figs. 39, 40, 41, 42, and 43 refer to the same parts. Fig. 40 shows the Westinghouse nose suspension. Nose *e* is connected to suspension bar *d*

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by link *f*; this construction allows sufficient side motion to

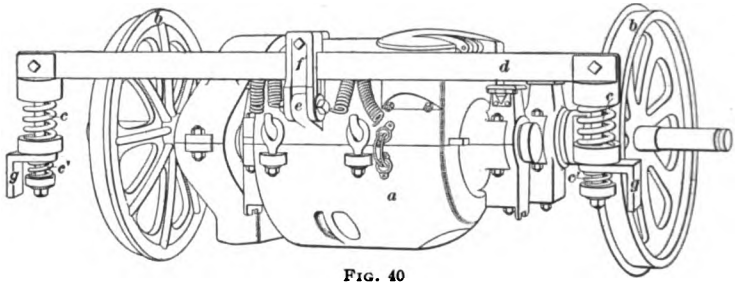

FIG. 40

prevent undue stresses on the rigging at curves and consequent loosening of suspension parts. Angle irons *g*, which

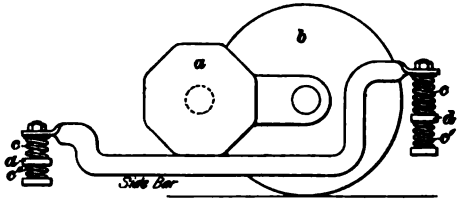

FIG. 41

support the suspension rigging, are riveted to the sides of the truck.

55. Side-Bar Suspension.—Figs. 41 and 42 illustrate two styles of **side-bar suspensions.** The motor is secured to the axle in the usual manner; two parallel spring-supported side bars, engaging the motor frame as shown, support the rest of the weight of the motor. Fig. 43 illustrates the actual construction of the Westinghouse side-bar suspension. The suspension bar itself is fastened to the truck sides, as indicated at *g* in Fig. 40.

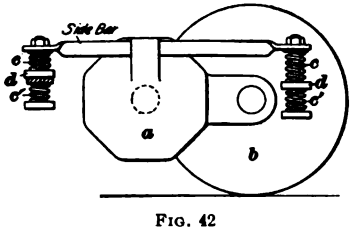

FIG. 42

56. Cradle Suspension.—Fig. 44 shows the **cradle suspension** as applied to a Westinghouse motor. The

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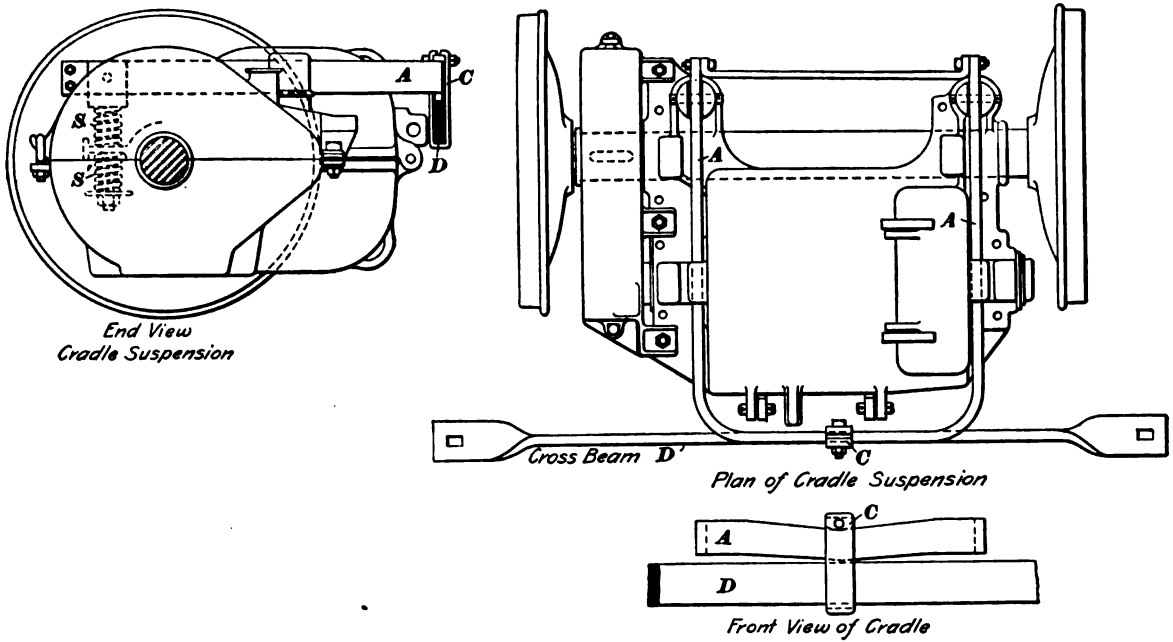

FIG. 44

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front of the cradle A is supported at C by the cross-beam D, which is supported by the side frames of the truck. The back end of the cradle is supported by springs S, S', which bear on lugs cast on the same arm that carries the axle bearing. The cradle passes through the lugs on the

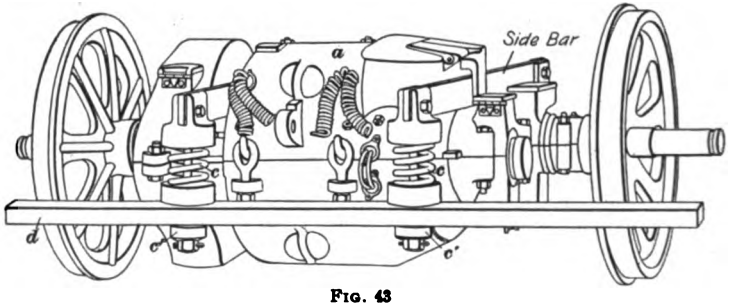

FIG. 43

sides of the motor, and the use of the springs insures a flexible suspension.

57. All other suspensions in use are modifications of the nose, side-bar, or cradle suspension. Whatever the suspension adopted, its parts must be kept tight; otherwise, failure of the rigging may let the motor down on the roadbed. In ordinary running over rough tracks, the motor jumps up and down, setting into action both sets of springs. To avoid rattling in the springs, the bolt that holds them should, when the motor is at rest and the car standing, have its nut screwed down until both springs are under a good compression; otherwise, when the weight of the motor for any reason acts with force enough to close the top spring, the bottom spring will rattle.

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SPEED CONTROL

RHEOSTATIC CONTROL

EFFECT OF RHEOSTAT

1. If a rheostat is connected in series with a railway motor across a line, a portion of the electromotive force of the line is expended in forcing current through the rheostat, and the remainder, in forcing current through the motor windings against their resistances and against the opposing action of the counter electromotive force of the motor armature. The electromotive force applied to the motor terminals is thus much lower than the line electromotive force. The counter electromotive force under these conditions is also much lower than that necessary when the full-line pressure is applied to the motor terminals.

When starting, about full-load current is allowed to flow through the rheostat and motor windings; therefore, with only a small part of the line electromotive force impressed on the motor terminals and with a fully excited field, the armature need only revolve at low speed in order to generate the proper counter electromotive force for the load conditions. Thus, if the motor is driving a car, the car speed will be low.

As the resistance in the rheostat is cut out, a higher electromotive force is applied to the motor terminals. The counter electromotive force also increases in order to prevent the impressed electromotive force from sending an excessive

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current through the motor, and the armature speed and the car speed are increased. This is the principle of rheostatic control of car motors.

SIMPLE CONTROLLER

2. The switch that is usually employed to regulate the speed of an electric car is called a **controller,** and in most cases one of these devices is installed at each end of the car. A very simple form of controller is shown in Fig. 1.

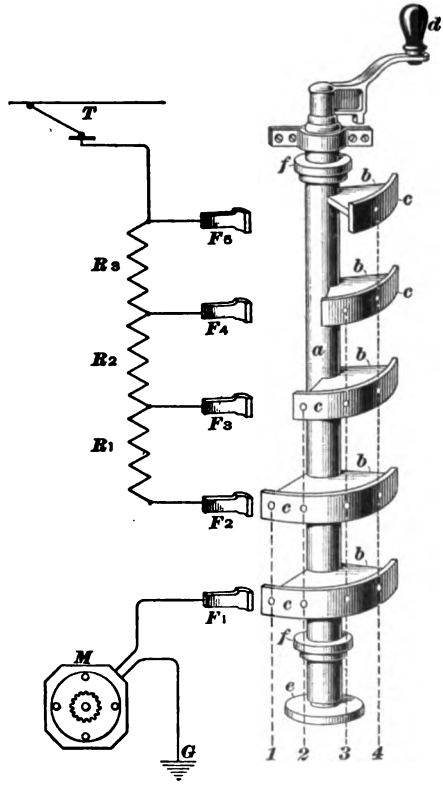

FIG. 1

An iron shaft *a* has projecting from it lugs *b*, on which are mounted copper segments *c*. The two lower segments are of the same length, but the others are of different lengths. The shaft is insulated from the handle *d* and the base *e* by insulating couplings *f*. The *brushes*, or *fingers*, which, when the shaft is turned, make contacts with the segments, are indicated at *F1*, *F2*, *F3*, *F4*, and *F5*. The last 4 fingers are connected to the resistance sections *R1*, *R2*, and *R3*. The trolley connection *T* is made at finger *F5*, and the motor connection *M* is made at finger *F1*. The dotted lines *1*, *2*, *3*, and *4* indicate the relative positions of the fingers on the segments when the segments are turned into contact with the fingers on the first, second, third, and fourth *notches* of the controller.

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When the shaft is at the off-position, no current flows in the motor circuit, because the circuit is interrupted between fingers *F1* and *F2*. At notch *1*, these two fingers are in contact with their segments, and as all the segments are connected together through their supporting lugs and the shaft, the motor circuit is now closed and current can flow from

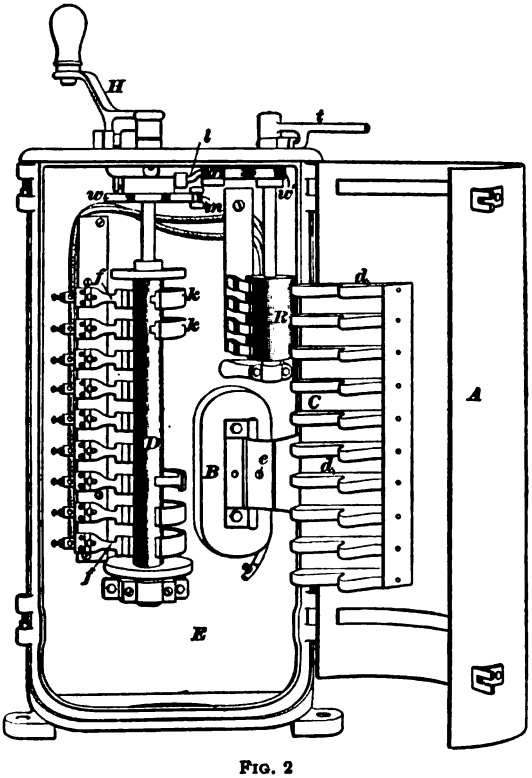

FIG. 2

the trolley wire through the three resistance sections and the motor to the ground at *G*. The motor starts and runs at low speed, because the electromotive force impressed on its terminals is low. At notch *2*, finger *F3* makes contact with its segment, and now resistance section *R1* is cut out, since fingers *F3* and *F1* are connected together. Movement of the shaft to notch *3* cuts out the resistance section *R2* as well

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as section *R1* by connecting fingers *F4* and *F1*; also resistance section *R1* remains cut out because fingers *F3* and *F1* still bear on their respective segments. When the shaft is turned to notch *4*, the last resistance section *R3* as well as sections *R2* and *R1* are cut out, since finger *F5* is now connected to finger *F1*. The speed of the motor increases as the resistance sections are cut out. On the fourth notch, therefore, the maximum speed is obtained for the given values of line electromotive force and motor load, since all the resistance sections are cut out and the line electromotive force is impressed on the motor terminals.

R-11 CONTROLLER

3. General Construction.—Fig. 2 shows a type of rheostatic controller designed by the General Electric Company for the control of cars, haulage locomotives, or hoisting motors. This controller is considered somewhat in detail, because it contains many of the features found in some of the more complicated types of controllers and serves as an introduction to the study of them. It is designed to handle one 50-horsepower, 500-volt motor or one 25-horsepower, 220-volt motor; that is, its contacts are large enough to handle about 75 amperes. The figure shows the cover *A* thrown back to expose the working parts. This controller is of the *magnetic blow-out type*, and is known as a **type R controller** because it uses rheostatic control. In the General Electric Company's controllers, a magnetic field is used to extinguish the arc that would otherwise form at the contact tips and cause blistering and burning; this method of preventing arcing has proved very effective. At *B* is shown the coil that sets up the magnetic field necessary to blow out the arc, and is therefore called the **blow-out coil.** The iron back of the controller *E* forms one pole piece and the polar extension *C* the other. Pole piece *C* is shown swung back to give access to the **power drum** *D*. When the controller is in use, the pole piece *C* is swung over and held in position by a bolt passing through hole *e*.

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Fig. 3, although not drawn to scale, will give an idea as to the relative positions of the pole piece *C*, the drum *D*, and the controller back *E* when the pole piece is swung into position. The pieces *d* are **arc guards,** made of vulcabeston or some other hard insulation. They pass between the contacts on the drum and also between the contact fingers; this prevents arcing from one finger to any of the others. The whole of the current supplied to the car passes through blow-out coil *B* and sets up a magnetic field between *N* and *S*, as indicated by the curved dotted lines. When the drum is revolved far enough, the tip *x* of contact ring *k* leaves finger *f* and an arc tends to form; on account of the reaction

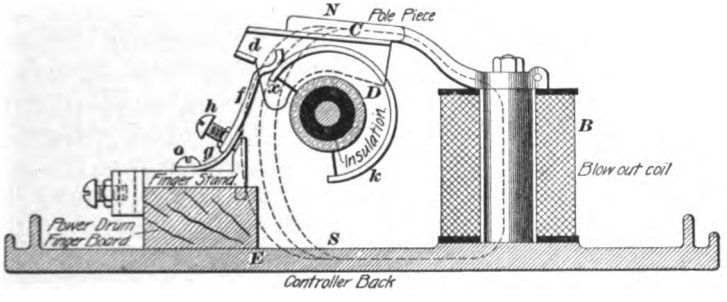

FIG. 3

of the lines of force of the arc and field, however, the arc is forced across the field and stretched until it is broken. The action is practically instantaneous, so that there is little or no burning of the fingers and contact tips.

The fingers *f* are stamped out of thick copper and are fastened to a flat phosphor-bronze spring *g*, which is, in turn, fastened to the cast-brass finger stand by means of screws *o*, so that fingers may be replaced at any time. The screw *h* is for adjusting the amount of drop of the fingers when the drum passes from under them. This affects the pressure with which the fingers press on the drum. They should be adjusted to drop $\frac{1}{32}$ to $\frac{1}{16}$ inch. The contact rings and tips should be rubbed frequently with a little vaseline to prevent wear and cutting.

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4. Star Wheel, or Index Wheel.—The power drum is operated by means of the power handle *H*, Fig. 2, which fits on the top of the power-drum shaft. In order to compel the power drum to take up a definite position corresponding to the various steps, it has a **star wheel**, or **index wheel**, *w* attached to the shaft. This engages with a spring-actuated roller *m*, which is pulled into the various notches on the star wheel and forces the drum into its proper position. The star wheel and roller give the movement of a controller handle its springy feeling.

5. Reverse Drum.—The reversing switch, or **reverse drum**, as it is called, is shown at *R*, Fig. 2. This drum is smaller and simpler than the power drum and is mounted in this controller near the upper right-hand corner. Its sole function is to reverse the armature connections, when it is desired to run the car in the opposite direction. The reverse drum is not intended to turn the current on or off or to effect any changes in the resistance; for this reason it is not provided with any device for suppressing arcing, and its contact fingers are somewhat lighter than those of the power drum.

6. Interlocking Device.—In order to insure that the reversing switch shall not be moved while the current is on, the controller is provided with an interlocking device that makes it impossible to move the reverse drum unless the power drum is at the off-position. The reverse-drum shaft is provided with a star wheel *w'*, Fig. 2, having three notches that correspond to the three positions—off, forward, and reverse. The lever carrying the roller *r* that engages this star wheel has attached to it a link *l* that runs across to the hub of the star wheel *w*. In the hub of *w* is a notch that comes opposite the end of *l* and engages with it when the power drum *D* and the reverse drum *R* are at their off-positions. When the reverse handle *t* is moved, the end of link *l* is forced farther into the notch until the roller *r* passes over the projection on the star wheel *w'*, when *l* falls back far enough to allow *D* to be turned. At any position of *D* other

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than the off-position, there is no notch opposite the end of *l*; hence, when an attempt is made to move *t*, the link *l* comes up against the hub and the reverse drum is locked.

When the reverse lever points ahead, the car runs forwards, and when it points back, the car runs backwards.

The reverse handle is also arranged so that it cannot be removed until the power drum is at the off-position. An L guard *a*, Fig. 4, is cast on the controller cap and overhangs a hook *b* cast on the handle. A notch *c* is cut in the guard so that the handle can be lifted off at the off-position and at no other.

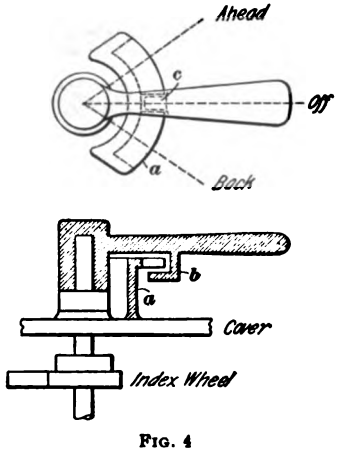

FIG. 4

One of the principal reasons for this interlocking arrangement is to make sure that the motorman will not reverse the motors while the power is on. In time of danger, the first thing the motorman would naturally do would be to reverse, or *plug*, the motors, and this is likely to cause trouble. If the power and reverse cylinders interlock, the motorman must throw off the power before he can throw the reverse switch. When the power is thrown on again, the resistance will be cut into circuit and there will be much less danger of any damage being done to the car equipment.

7. Controller Connections.—The foregoing will give an idea as to the mechanical construction of this controller. It has six notches, and a development of the drum with the various connections is shown in Fig. 5. This diagram shows a single motor, of which A' and F' are the armature and field, respectively. It is operated by a single controller. In this controller figure, the drum contact rings are indicated by black bands, which represent the rings straightened or flattened out. The finger stands on the power- and reverse-

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drum connection boards are represented by the row of square black spots, which also indicate the general positions of the fingers. The vertical dotted lines indicate the relative positions of the fingers on the segments when the segments are moved into contact with the fingers on the different notches of the controller. Note that the drum is

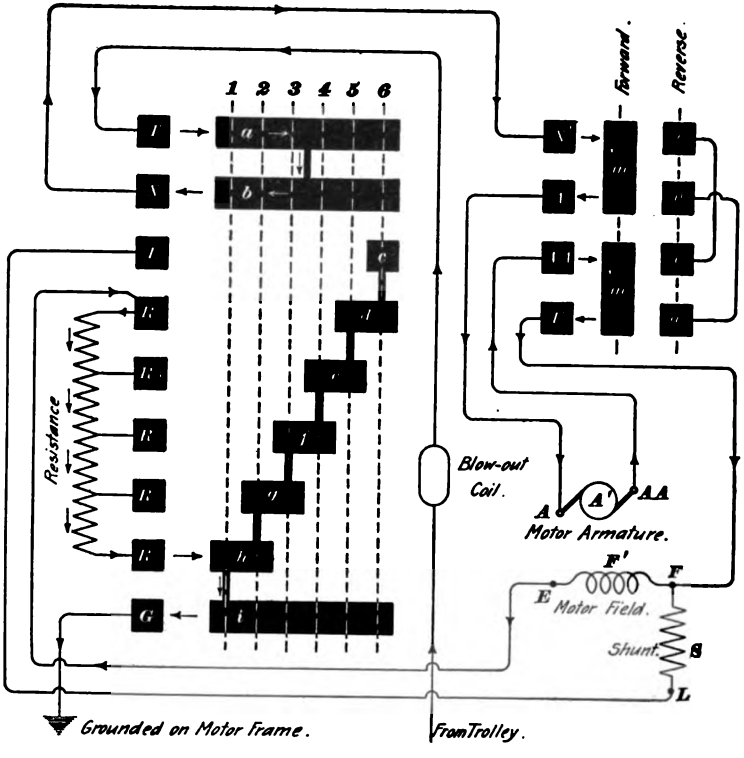

FIG. 5

in two parts. Contact segments *a* and *b* are connected together, but these two are insulated from segments *c*, *d*, *e*, *f*, *g*, *h*, and *i*, which are all connected together, because they constitute a single casting. On the first notch, fingers *T*, *X*, *R1*, and *G* make contact with their respective segments. All the other fingers hang over the drum, but do not make contact with the drum segments.

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The path of the current on the first notch, with the reverse switch at forward position, is indicated by the arrowheads, and is as follows: Trolley–blow-out coil–*T*–*a*–*b*–*X*–*X'*–*m*–*A*–*A*–armature *A'*–*AA*–*AA*–*n*–*F*–*F*–field *F'*–*E*–*R5*–through the whole of the resistance–*R1*–*h*–*i*–*G* to ground, thus completing the circuit from the trolley to the rail.

On the second notch, finger *R2* touches contact segment *g*, and when the current reaches *R5* it flows through three sections only of the resistance, because when it reaches *R2* it takes the path *R2*–*g*–*h*–*i*–*G*. On the third notch, the section of resistance between *R2* and *R3* is cut out. On the fourth notch, that between *R3* and *R4* is cut out. On the fifth notch, all the resistance is cut out, and the path of the current is: trolley–blow-out coil–*T*–*a*–*b*–*X*–*X'*–*m*–*A*–*A*–*A'*–*AA*–*AA*–*n*–*F*–*F*–*F'*–*E*–*R5*–*d*–*e*–*f*–*g*–*h*–*i*–*G*. The fifth notch, then, gives the highest speed that can be attained by simply cutting out resistance.

On this controller, a *shunt resistance S* may be used and a sixth notch is provided, so that on this notch the shunt will be connected across the motor field coil. Only a portion of the main-motor current flows through the field coil when the shunt is active, and the remainder of the current flows through the shunt. The field is therefore weakened, and the motor armature must revolve faster in order to generate the proper counter electromotive force for the load conditions. The car speed will thus be higher than when the shunt is not used. One end of the shunt is attached to *F* and the other end to finger *L*. On the sixth notch, the path of the current is the same as on the fifth notch up to the point *F*; here the current divides, part of it taking the path *F*–*F'*–*E*–*R5*–*d*–*e*–*f*–*g*–*h*–*i*–*G*, and the other part, the path *F*–*S*–*L*–*L*–*c*–*d*–*e*–*f*–*g*–*h*–*i*–*G*, thus taking part of the current away from the field.

If the motor is to be reversed, the reverse switch is thrown over, bringing contacts *t*, *u*, *v*, *w*, under fingers *X'*, *A*, *AA*, and *F*, respectively. When the current reaches *X'*, it takes the path *X'*–*t*–*v*–*AA*–*AA*–*A'*–*A*–*A*–*u*–*w*–*F*. In other words, it flows in at the *AA* end of the armature instead of at the

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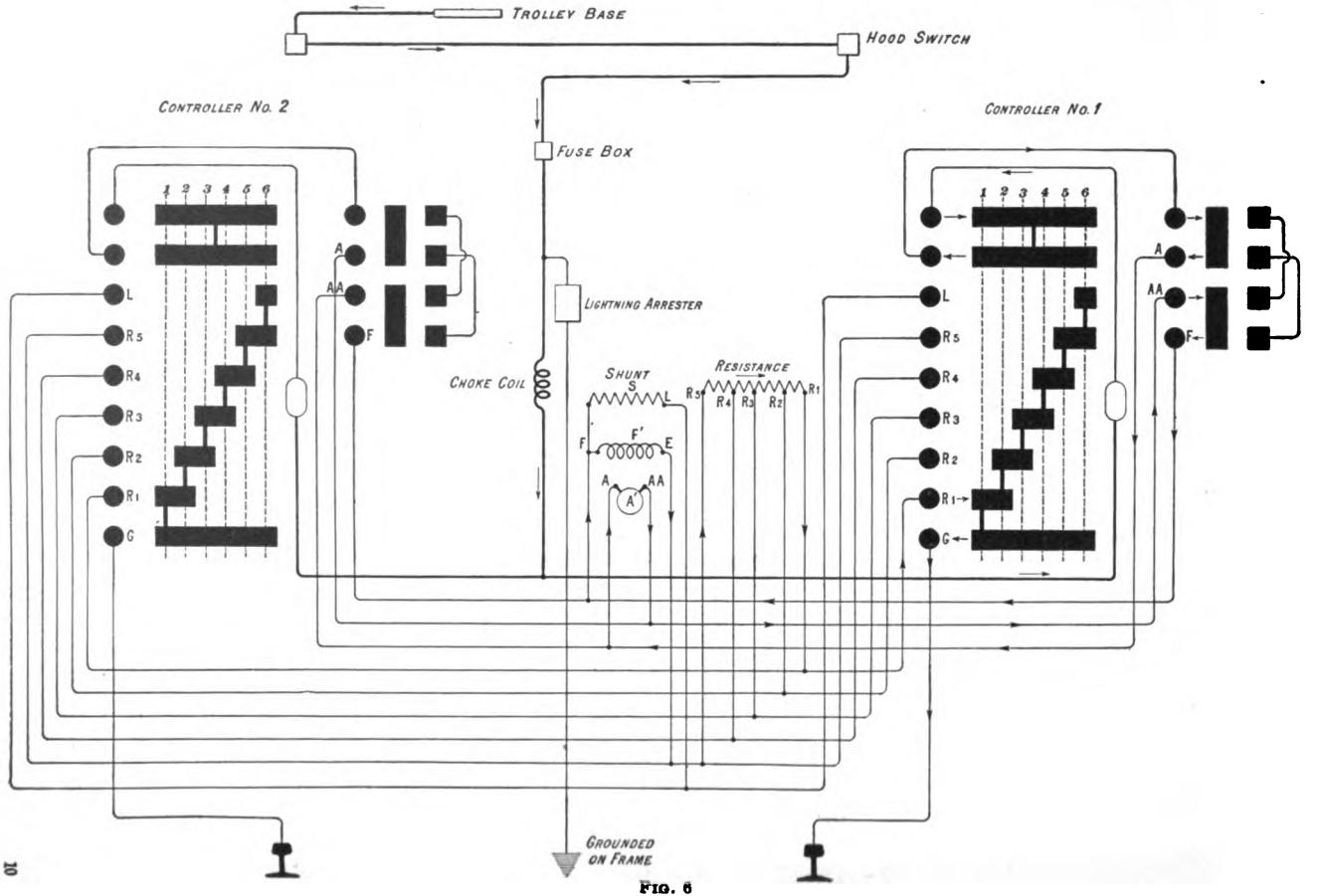

FIG. 6

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A end as before, but it still flows in at the *F* end of the field, thus reversing the current through the armature, but not through the field. The lettering of the various connecting posts in the controller is similar to that used by the General Electric Company.

8. Car-Wiring Diagram.—In Fig. 5 only one controller is shown so as to simplify matters; but on a car, two controllers, one on each end, are usually necessary. Fig. 6 shows two of these controllers connected to operate a single motor, with

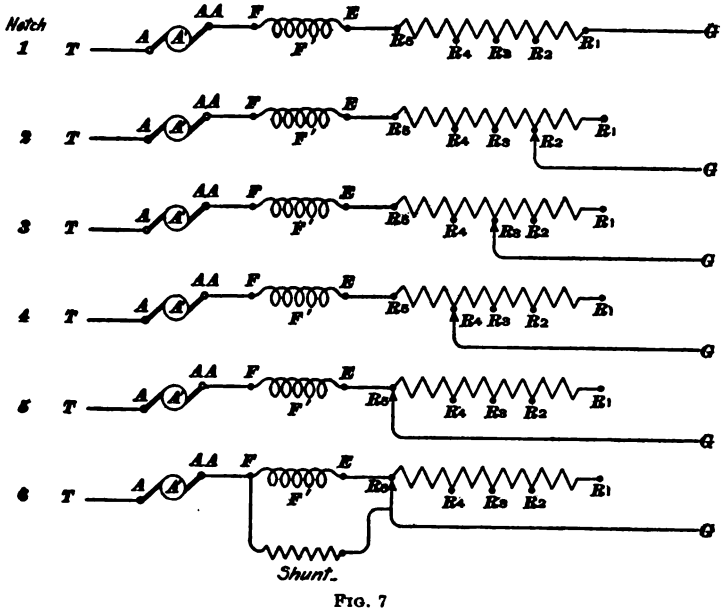

FIG. 7

the parts arranged in about the relative positions they would occupy on the car. The corresponding connecting posts of the two controllers are connected together by the long wires that run the length of the car. When one controller is in use, the other is at the off-position. The arrowheads show the path of the current when controller No. *1* is on the first notch. This path is practically the same as that shown in Fig. 5. The current passes through both hood switches, Fig. 6, and the fuse box before reaching the controllers. The wires in this dia-

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gram are not supposed to touch each other where they cross, unless there is a round dot placed at their point of intersection. In order to become familiar with the method of representing the car wiring, it will be well to trace out the path of the current on the other notches. The various combinations may be represented diagrammatically, as shown in Fig. 7. The first five steps differ from each other in the amount of resistance included, and the last step is the same as the fifth, with the exception that the field F' is shunted.

When a rheostat is used continuously to control the speed, it must be proportioned so as to avoid overheating, and all the resistance notches may be used as running notches. With ordinary electric cars, however, the resistance is not supposed to be used for speed-controlling purposes. It is only used to give the car a smooth start and should not be used to run on. Before leaving the study of this controller, it may be well to notice that the resistance coils are here placed next to the ground, so that the current enters the motor first. In most controllers, the resistance is placed ahead of the motors, but, on the whole, it makes no difference so far as the effect of the resistance itself goes; sometimes, however, it does make a difference in regard to the amount of trouble that arises on account of grounds occurring on the resistance.

9. Reverse-Switch Connections.—In Fig. 6 the post marked *AA* on controller No. *1* is connected to post *A* on controller No. *2*, and post *AA* on controller No. *2* is connected to post *A* on controller No. *1*. This is done in order that the current may flow through the motor windings in such a direction that the car may always run forwards when the reverse handle on the end from which it is being run points ahead.

In Fig. 8 (*a*) are shown a motor and the fingers and forward contact strips of two reverse switches. With proper connections of the car wires, the car will move toward the north when the No. *1* controller is used with its reverse handle pointing forward, and toward the south when the

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No. 2 controller is operated with its reverse handle pointing forward. Consider the No. 1 reverse switch. Current enters at 19, Fig. 8 (*a*), and flows as follows: *19–1–A–A–AA–AA–2–F–F–E–G*. The direction of flow of the current through the armature and field is as shown in Fig. 8 (*b*), and the rotation of the armature is assumed to be in a clockwise direction and to drive the car, through the motor gears, toward the north, or in a forward direction, when the car is being operated from the No. 1 controller.

Trace the path of the current when the No. 2 reverse switch is in action. The flow of the current through the

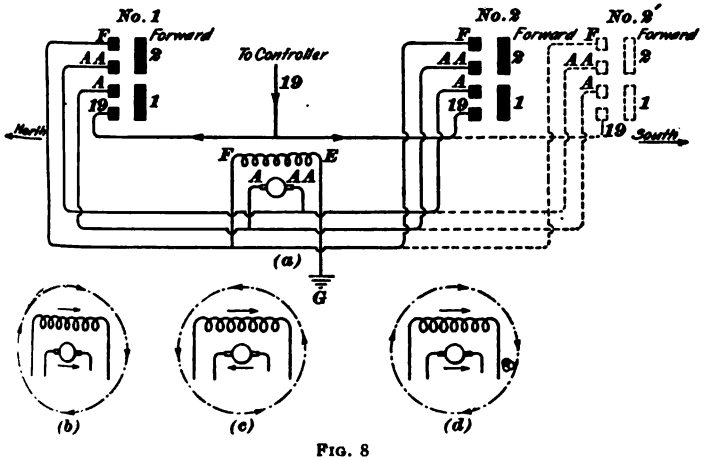

FIG. 8

field coil is in the same direction as before, but through the armature it is in the opposite direction. Fig. 8 (*c*) indicates the direction of flow of the current and a counter-clockwise rotation of the armature, which will drive the car in the direction opposite to its previous line of motion. As the No. 2 switch is on the other end of the car, the new direction of rotation will drive the car toward the south, or in a forward direction, when the end of the car on which the No. 2 reverse switch is mounted is considered as being temporarily the front end.

If the armature terminals were not reversed on the No. 2 reverse switch, but both switches were connected exactly

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alike, the conditions would be as indicated by No. *1* and No. *2'* switches. Trace the path of the current when No. *2'* switch is in service. The direction of flow of the current and of the armature's rotation is shown in Fig. 8 (*d*), which is the same as Fig. 8 (*b*), and the car will be driven by the motor and its gearing toward the north. Considering the No. *2'* end as the front end, the car will move backwards when the reverse handle on the No. *2'* reverse switch is on its forward position. The car will obey the reverse switch when the No. *1* reverse switch is in operation, but will disobey the reverse switch when the No. *2'* reverse switch is in operation. The proper connections for the reverse switches are those shown for the No. *1* and No. *2* switches. The car should obey the reverse switch at either end in order to prevent confusion when, in case of an emergency, the motorman endeavors to stop the car by reversing the motors.

SERIES-PARALLEL CONTROL

DISTRIBUTION OF VOLTAGE

10. The method of speed control now almost universally used for direct-current railway work is known as the **series-parallel method.** It enables the voltage applied to the motors to be cut down for low-speed running without the use of resistance, and hence is more economical on low speeds than the rheostatic method. At least two motors per car are required; hence, this method is not applicable to single-motor equipments. For low speed, the motors are connected in series, and for high speed, they are connected in parallel; hence the name series-parallel.

Assume that the pressure is 500 volts; then, if the two motors on a car are connected in series, as shown in Fig. 9, the pressure across each motor will be only 250 volts. Each motor will then have to run at only about half its normal speed to generate the required counter electromotive force; thus, a low speed is obtained without the use of any resistance.

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When the higher speed is desired, the controller is turned through the transition notches to the parallel notches and effects the combinations necessary to change the motors from series to parallel connection. When they are in parallel, as shown in Fig. 10, a pressure of 500 volts is applied to each motor and the car runs at full speed. Of course, at starting

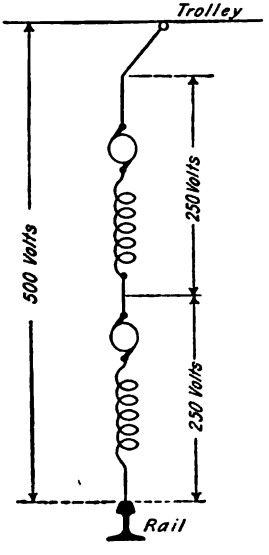

FIG. 9

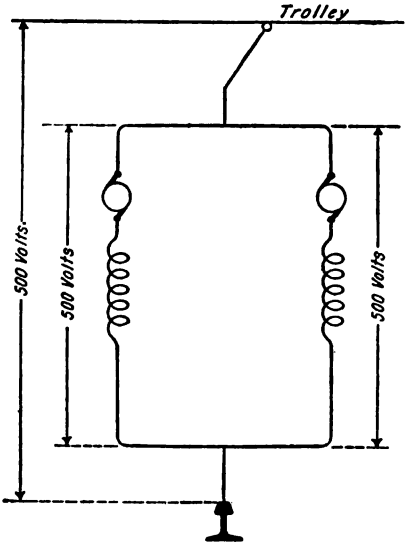

FIG. 10

it is necessary to include some resistance, and when changing from series to parallel through the transition notches, resistance is also cut in to prevent an excessive rush of current and to give a smooth acceleration to the car; but the resistance is cut out as soon as the car gets under headway and is not used on the running notches.

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TYPES OF CONTROLLERS

TYPE LETTERS

11. The General Electric Company's controllers for electric cars are divided into several classes, or types.

Type R controllers include all controllers that control either by means of resistance in the armature circuit only, or by means of resistance in the armature circuit and field regulation only.

Type K controllers are intended for two or more series motors, and include the feature of shunting, or short-circuiting, one of the motors when changing from series to parallel connection. For ordinary street cars, the K type of controller is almost universally used.

Type L controllers are also intended for two or more series motors, but in changing from series to parallel connection, the power circuit is completely opened for an instant and then closed after the change from series to parallel connection has been made. Type L controllers are used mostly for interurban cars equipped with large motors.

Type B controllers may be either rheostatic or series-parallel control, but they are always provided with the necessary contacts and connections for the operation of electric brakes.

Type C controllers include all master controllers for use with the General Electric type M system of multiple-unit control. This system of control is explained in another Section.

Type T controllers include all hand controllers for use with alternating-current motors.

Westinghouse series-parallel controllers are designated in the same way as those of General Electric make, and their construction is also the same.

Westinghouse controllers for unit-switch control are usually designated by a type number, which in some cases is followed by a letter.

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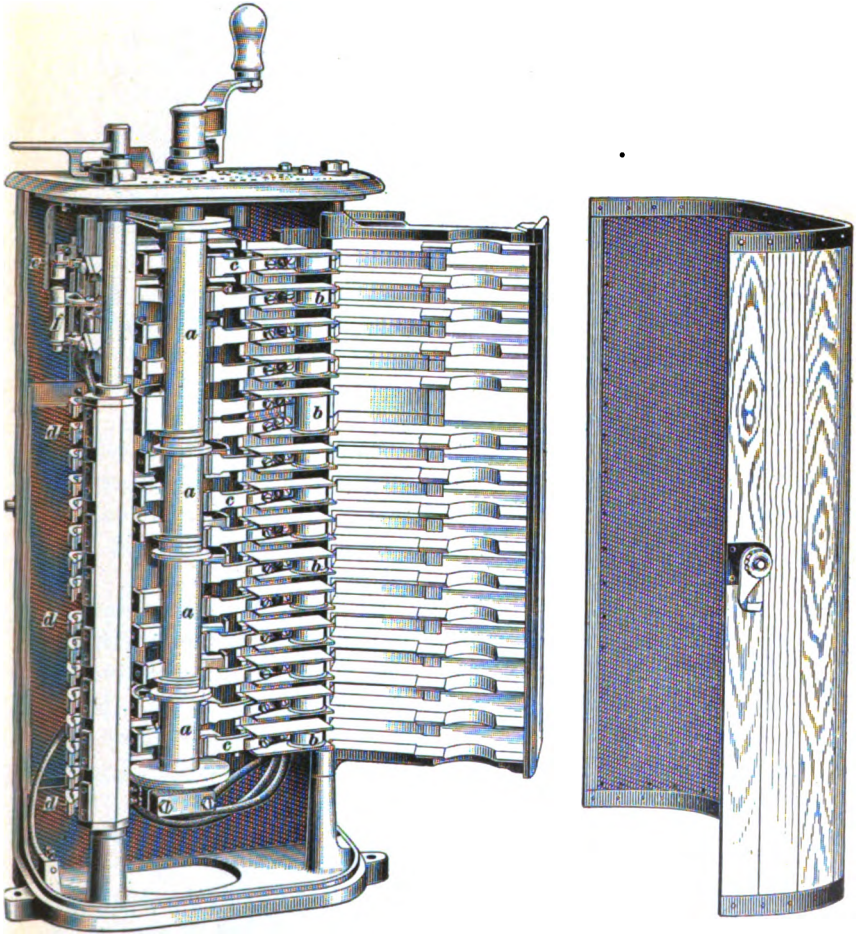

FIG. 11

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DESCRIPTION OF K-35 CONTROLLER

12. In Fig. 11 is shown a **K-35 controller** designed for use with either two 100-horsepower or four 50-horsepower motors, as well as for use with motors of less capacity. This controller differs in several respects from the earlier controllers of the K type. A number of small blow-out coils are used instead of one large coil; the terminals for the leads entering the controllers are attached directly to the finger bases, thereby obviating the necessity for the separate connection board used on most controllers of the K type; the reverse cylinder is longer and is located in the left-hand side of the controller box instead of in the right-hand upper corner, as is the usual custom; and the cut-out switches are near the top of the box, instead of the bottom as in other types.

13. Four cylinder castings *a*, Fig. 11, each of which bears two or more contact segments, are mounted on the main controller shaft. Each casting is insulated from the shaft and from the other castings, and is so arranged that it may be readily removed and replaced if necessary.

The arcs that may form between the contact segments and the fingers are blown out by the action of the individual blow-out coils *b*. The steel cores of these coils are riveted to steel flanges that are fastened to the finger bases. Steel plates are also imbedded in the arc-deflector partitions and are thereby electrically insulated from the controller frame. The magnetic flux is thus directed across the arc at right angles to it, and the arc is blown out. This effect is due to the interaction between the magnetic lines set up around the arc, caused by the current flowing in it, and the magnetic flux set up by the blow-out coil. The action is similar to that between a motor armature conductor and the motor field, as explained in the first portion of *Direct-Current Dynamos*.

The power-drum fingers are shown at *c*, and the reverse-drum fingers at *d*. The cut-out switches *e* and *f* allow a

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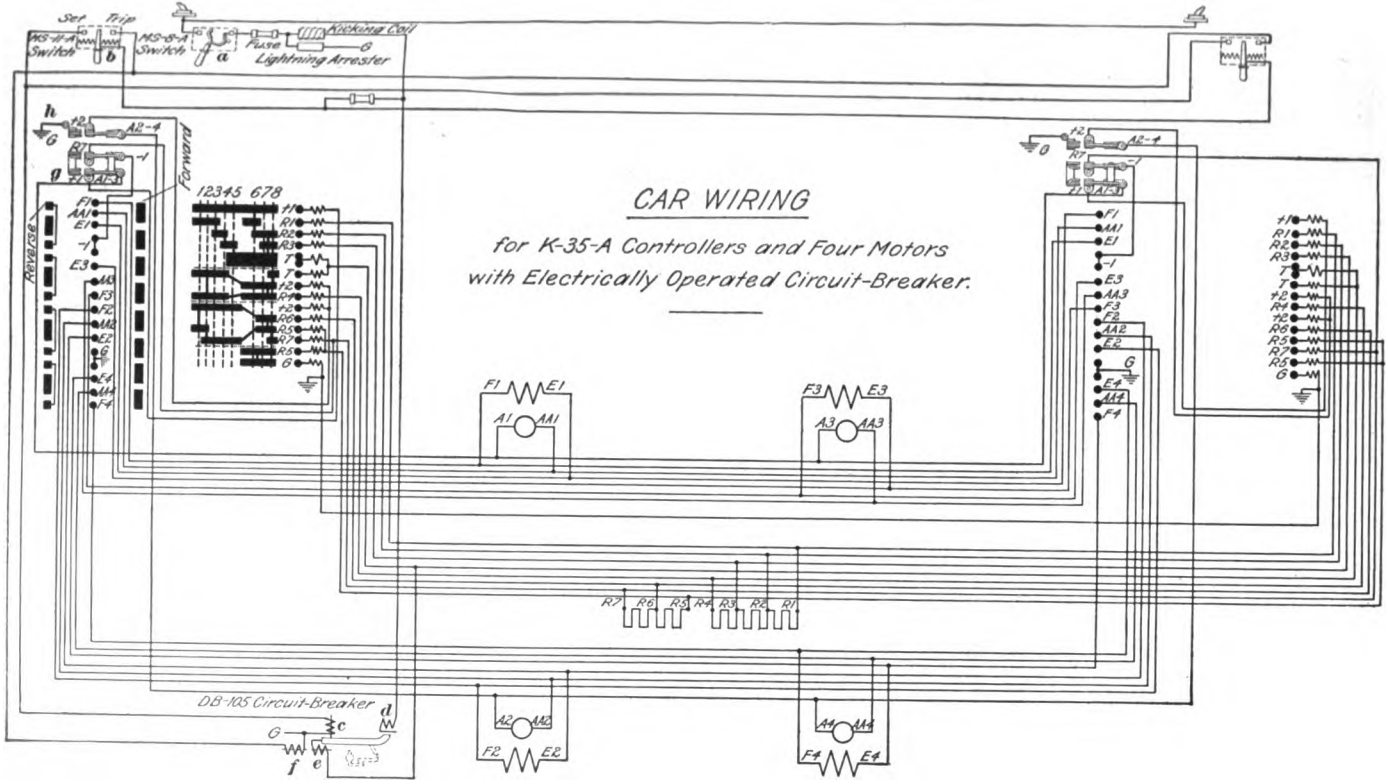

FIG. 12

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faulty motor, or pair of motors, to be cut out of circuit and the car to be operated on the remaining motor or pair of motors.

K-35 CAR-WIRING DIAGRAM

14. Electrically Operated Circuit-Breaker. — In Fig. 12 is shown a car-wiring diagram for two K-35-A, series-parallel controllers and four motors with an electrically operated circuit-breaker. Fig. 13 shows the MS-8-A switch, which is used as a hood switch. This is the main hand-operated switch of the car outfit. An electrically operated circuit-breaker of the DB type is shown in Fig. 14. The circuit-breaker, enclosed in an iron box, is usually mounted underneath the car.

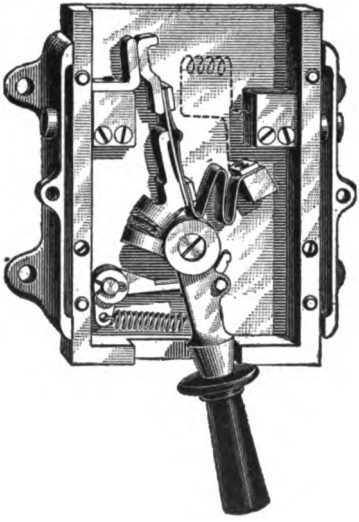

FIG. 13

In Fig. 15 is shown a MS-11-A switch, which is used as a circuit-breaker setting and tripping switch. One of these switches is installed at each end of the car, and by the operation of either switch, the circuit-breaker may be opened or closed independent of the action of the main current flow through the circuit-breaker.

15. To start the car, the main switch *a*, Fig. 12, is first closed. Switch *b* is then thrown so that its left-hand contact, marked *set*, is active. Current can now flow through switches *a* and *b* and through setting coil *c* in the circuit-breaker to the ground at *G*. Coil *c* corresponds to coil *b*, Fig. 14. When this coil is energized, its armature is drawn up and this forces the circuit-breaker switch into its closed position.

The *T* fingers on the controller, Fig. 12, are now connected through the closed circuit-breaker to switch *a*. Coil *d*,

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Fig. 12, is a blow-out coil and is located at *a*, Fig. 14. Coil *e*, Fig. 12, is the automatic trip coil. In case of an overload, this coil automatically opens the circuit-breaker. The coil is not shown in Fig. 14, but is located just to the right of *c* in that figure.

If switch *b*, Fig. 12, is thrown so that its right-hand contact, marked *trip*, is active, tripping coil *f* in the circuit-breaker is energized and acts to release the catch that keeps the circuit-breaker closed, and thus opens the breaker. This tripping coil is shown at *c*, Fig. 14. Resistance coils *d*, Fig. 14, are in circuit with the control tripping coil in order

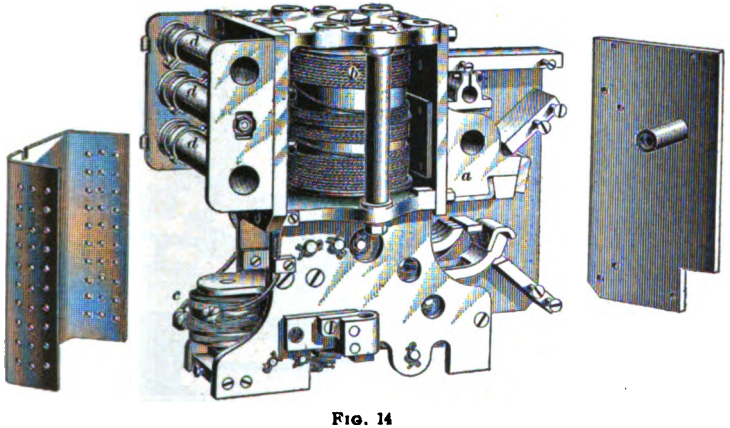

FIG. 14

to reduce the current flow. The circuit-breaker, Fig. 12, may be automatically opened by an overload, or it may be opened or closed by means of the control coils operated by the motorman.

16. Series Notches.—When the controller, Fig. 12, is thrown to the **first notch,** the fingers bear on the contact segments at the positions indicated by the crossings of the heavy lines representing the segments and the vertical dotted line *1*. The reverse switch is assumed to be in the *forward* position. Current flows from lower finger *T–R4–R4*–three sections of resistance–*R1–R1–* + *1–* + *1–*(*A1-3*)– then in parallel through motors Nos. *1* and *3* as follows:

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$\left\{\begin{matrix} A1\text{–}AA1\text{–}AA1\text{–forward reverser segment–}F1\text{–}F1\text{–}E1\text{–}E1\text{–} \\ A3\text{–}AA3\text{–}AA3\text{–forward reverser segment–}F3\text{–}F3\text{–}E3\text{–}E3\text{–} \end{matrix}\right.$ $\left.\begin{matrix} -1 \\ -1 \end{matrix}\right\}$ *–1–R7–R7* on rheostat–two sections of resistance–*R5*–upper finger *R5*–lower finger $+2$– $+2$–(*A2-4*)–then in parallel through motors Nos. *2* and *4* as follows:

$$\left\{\begin{matrix} A2\text{–}AA2\text{–}AA2\text{–}F2\text{–}F2\text{–}E2\text{–}E2\text{–}G \\ A4\text{–}AA4\text{–}AA4\text{–}F4\text{–}F4\text{–}E4\text{–}E4\text{–}G \end{matrix}\right\}\text{–ground}$$

Motors Nos. *1* and *3* are in parallel and form one pair of motors; motors Nos. *2* and *4* are also in parallel and form

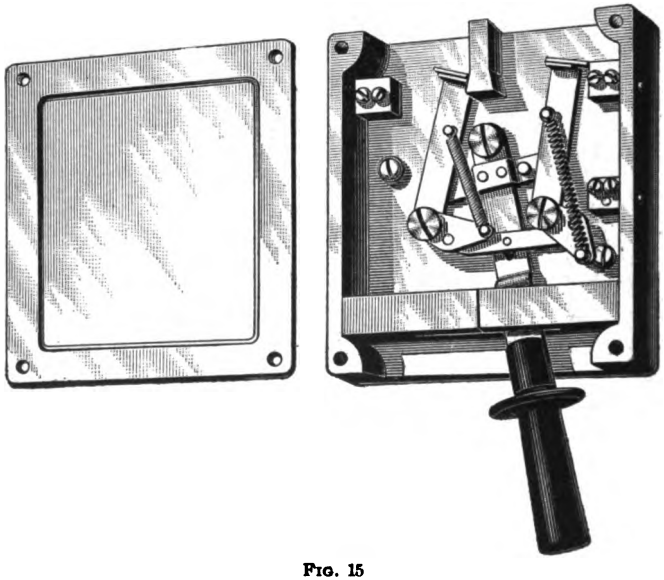

FIG. 15

the other pair of motors. The two pair of motors are in series and these, in series with five sections of resistance, are connected between the trolley wire and the ground. The motor connections are as shown at notch *1*, Fig. 16.

On the **second notch**, Fig. 12, the only change in the controller connections is that finger *R7* bears on a segment, and as this segment is part of the same casting as the segment on which lower finger $+2$ bears, current can flow from

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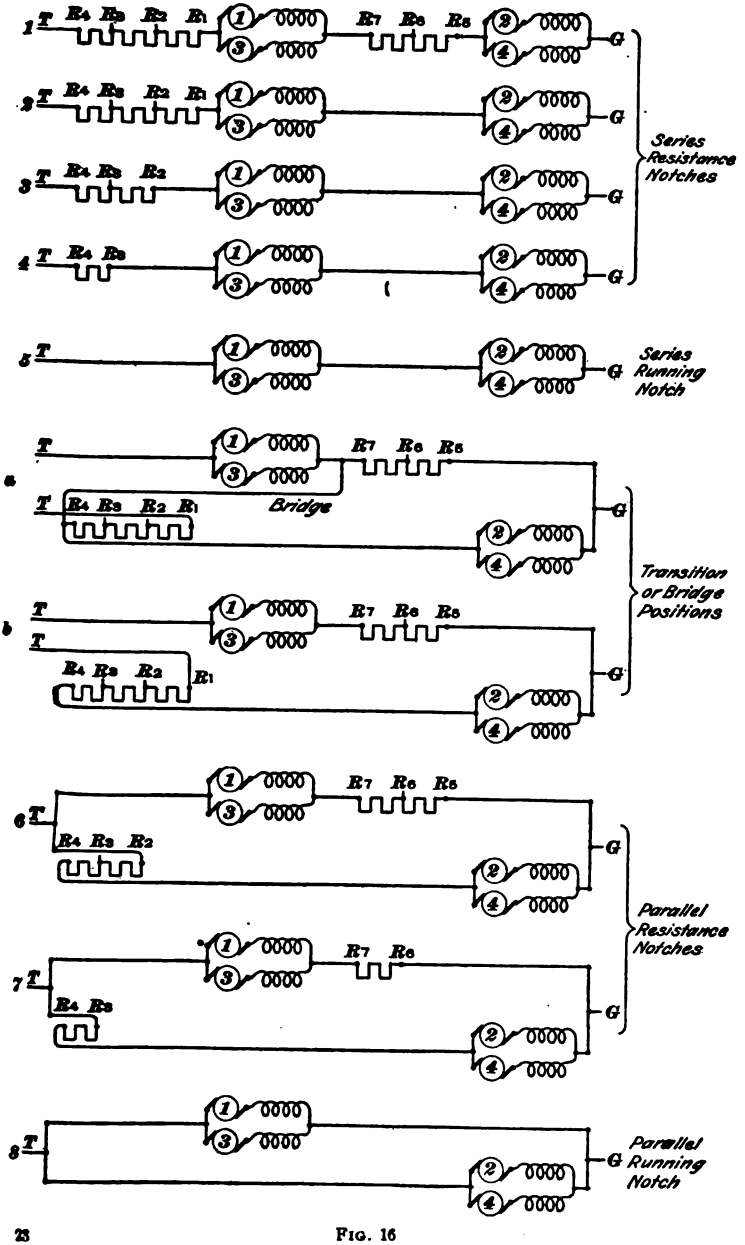

FIG. 16

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R7 on the cut-out switch–finger *R7*–casting–lower finger +*2* and through motors Nos. *2* and *4* to the ground. The two resistance sections *R7* to *R5* are thus cut out of circuit. See notch *2*, Fig. 16.

On the **third notch**, Fig. 12, finger *R2* is active and the current can flow from lower finger *T*–*R4*–*R4*–two sections of resistance–*R2*–finger *R2*–casting–finger +*1*– +*1*–two pair of motors in series to the ground. One more section of resistance is cut out. See notch *3*, Fig. 16.

On the **fourth notch**, Fig. 12, finger *R3* is active, and the resistance section between *R2* and *R3* is cut out. The motor connections are now as shown at notch *4*, Fig. 16.

On the **fifth notch**, Fig. 12, upper finger *T* is active and current can flow through the casting to finger +*1* and through the motors to the ground. The last section of resistance is cut out, and the pairs of motors are in series across the line. See notch *5*, series running notch, Fig. 16.

17. Transition, or Bridge, Positions.—After the controller is turned from the fifth notch, Fig. 12, fingers *R3*, lower *2*, and *R7* drop contact with their segments. Fingers *R1*, upper *2*, *R4*, lower *R5*, and *G* make contact with their segments. Finger *R1* makes contact at practically the same time that lower finger *2* leaves contact with its segment. As soon as finger *R1* makes contact, the pairs of motors are connected in parallel. Current flows from upper finger *T*– +*1*–motors Nos. *1* and *3* in parallel– –*1*– –*1*–*R7*–*R7* on rheostat–*R5*–lower finger *R5*–*G*. Current also flows from upper finger *T*–*R1*–*R1*–*R4*–*R4*–upper finger +*2*– +*2*–motors Nos. *2* and *4* in parallel–*G*. All the motors are now in parallel, with resistance sections connected in circuit. For the instant when finger *R1* is bearing on its segment and upper finger +*2*, lower finger +*2*, finger *R4*, and finger *R7* are bearing on their segments, a bridge connection is made between fingers *R7* and *R4* through *R7*–casting–lower finger +*2*–upper finger +*2*–casting–*R4*. The bridge connection is shown at *a*, Fig. 16. This connection is soon broken and the connections are then as at *b*.

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18. Parallel Notches.—On the **sixth notch,** Fig. 12, which is the first of the regular parallel resistance notches, finger *R2* is again active and one resistance section is cut out of the circuit of the pair of motors, Nos. *2* and *4*. The two pair of motors are now in parallel, and there are two resistance sections in series with each pair of motors. See notch *6*, Fig. 16.

On the **seventh notch,** Fig. 12, finger *R6* is active and current can flow from *R7* at the cut-out switch–*R7* on the rheostat–one section of resistance–*R6*–finger *R6*–casting –upper finger *R5*–lower finger *R5*–casting–ground. Only one section of resistance is now left in circuit with the pair of motors, Nos. *1* and *3*. Finger *R3* is also active, and this cuts out one of the sections of resistance in series with the pair of motors, Nos. *2* and *4*, thus leaving only one section of resistance in that circuit active. See notch *7*, Fig. 16.

On the **eighth notch,** Fig. 12, finger *R7* is active and current can flow from *R7*–casting–*R5*–*R5*–to ground. The last section of resistance in series with the pair of motors, Nos. *1* and *3*, is cut out. Lower finger *T* is also active and current can flow to the casting–finger +*2*–motors Nos. *2* and *4*, to the ground. The last section of resistance in series with the pair of motors, Nos. *2* and *4*, is cut out. This is the parallel-running notch, and the pairs of motors are in parallel with all resistance sections cut out. See notch *8*, Fig. 16.

19. Reverse Switch.—If the reverse switch, Fig. 12, is thrown to the reverse position, the direction of current flow through the motor armatures remains unchanged, but the direction of current flow through all the motor field-coil circuits is reversed. The motors will then drive the car backwards. In these reverse switches the armature wires are connected in a similar manner to both switches, but the field wires are reversed in one controller from their connections in the other controller. This is done in order that the car will obey the reverse switch at either end. If the motors were not connected in this manner, confusion might ensue regarding the proper position of the reverse-switch handle.

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20. Braking by Reversing.—The car may be stopped suddenly by throwing the main controller handle to off-position, throwing the reverse handle to its reverse position, and then advancing the main controller handle. The motors will then tend to drive the car in the direction opposite to the direction that the momentum of the car is driving it, and the car will come to a sudden halt; also, if the current is left on, the car will reverse its direction of motion. This action causes very severe stresses on the apparatus, and the car should be reversed only in case of an emergency.

21. Cut-Out Switches.—Cut-out switches are used to disconnect a faulty motor or the pair of motors that includes the faulty motor. Suppose that the cut-out switch *g*, Fig. 12, is thrown over to the left. It enters a clip that connects one switch blade directly to the other blade. If the controller is on the first notch, current can flow from lower finger *T*–*R4*–three sections of resistance–*R1*–finger +*1*–then directly from the +*1* wire to the *R7* wire, through the two sections of resistance between *R7* and *R5*, and through the pair of motors Nos. *2* and *4*, to the ground. The other pair of motors are thus cut out of circuit. The controller cannot be advanced beyond the fifth notch when either cut-out switch is thrown to the left.

Suppose that cut-out switch *g* is now thrown to its normal position, to the right, and that cut-out switch *h* is thrown to the left. On the first notch, current flows through the three resistance sections between *R4* and *R1*, the pair of motors, Nos. *1* and *3*, wire *R7*, the two resistance sections between *R7* and *R5*, wire +*2*, and directly to ground through switch *h*. The other pair of motors is cut out.

22. Designation of Car Wires.—In almost all car-wiring diagrams, the No. *1* armature terminals are designated as *A1* and *AA1*, and those of the No. *2* armature as *A2* and *AA2*. Where four motors constitute an equipment, the No. *3* armature terminals are designated as *A3* and *AA3*, and those of the No. *4* armature as *A4* and *AA4*. The standard designations for field terminals are *F* and *E*, a number being added

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to indicate to which motor the terminal belongs. Thus, *F1* and *E1* indicate the positive and negative field terminals, respectively, of the No. *1* motor; *F2* and *E2*, the same for the No. *2* motor; *F3* and *E3*, for the No. *3* motor; and *F4* and *E4*, for the No. *4* motor.

As each motor terminal connects to the controllers through a car wire, the result is that the motor terminal, the car wire, and the controller terminal on one controller, to which the motor terminals connect, take the same name. Thus, the left-hand No. *1* armature terminal, Fig. 12, is marked *A1*; accordingly, the car wire to which it taps is the *A1* wire and this wire connects to the *A1* terminal of the lower cut-out switch at each end of the car, but, for reasons already given, the *F1* terminal of the No. *1* motor is connected to the *F1* reverse-switch finger in one controller and the continuation of the same car wire is connected to the *E1* reverse-switch finger in the other controller.

MOTOR CONNECTIONS

23. When two motors are placed on a single truck, it is customary to install them back to back, with the commutator ends of the two motors toward opposite sides of the truck. The current must be led through the armatures and field coils of the motors in such a manner that both motors aid in propelling the car.

In Fig. 17 (*a*), the car is driven in the direction indicated by the arrow *B*. The armature of the No. *1* motor must turn in a clockwise direction in order to turn the gear on the axle shaft in a counter-clockwise direction and drive the car forwards. The arrowheads on the circles marked *W* and *A* indicate the direction of rotation of the wheels and armature. The motor is being observed from its commutator end. The current flowing through brush *1*–No. *1* armature–brush *2*–*a* field coil–*b* field coil is assumed to make *a* a north pole, the top of the armature a north pole, and *b* a south pole. This causes a clockwise rotation, as the north pole on the armature is attracted toward the south field pole. If the No. *2* motor

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were set directly over the No. *1* motor, with the commutator ends near the same side of the truck, the motors would be connected exactly alike; that is, the current would flow through the armatures and field coils of both motors in the same direction, and both pinions, acting on the same side of the axle gear, would drive the car toward the north, or forwards,

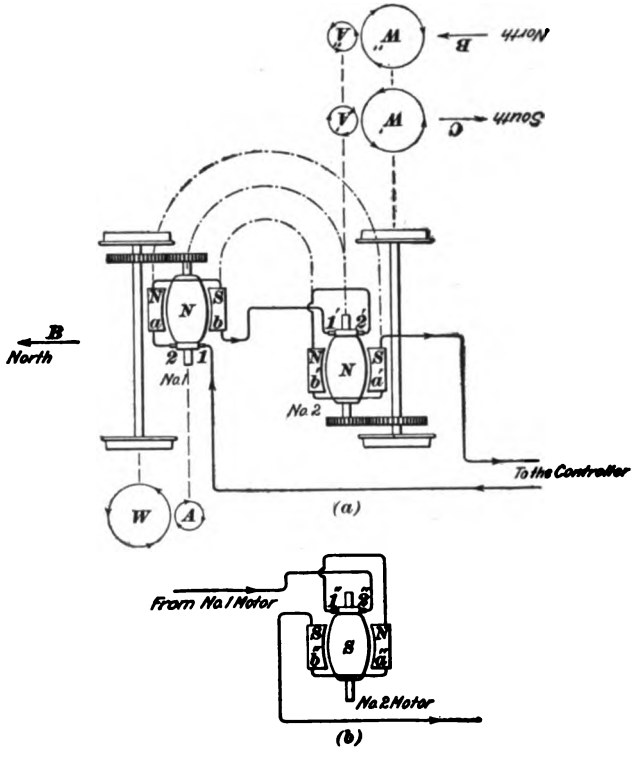

FIG. 17

the front of the car being considered as the end on which the No. *1* motor is installed.

24. No. *2* motor is now assumed to be taken from its position over the No. *1* motor and placed in its proper position on the rear axle, as shown in Fig. 17 (*a*). The commutator end of the No. *2* armature is now near the opposite side

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of the truck. If the connections were not disturbed and current were sent through the motor circuit, the No. *2* armature, regarded from the commutator end, would tend to rotate in a clockwise direction, as before. Turning Fig. 17 (*a*) so that the No. *2* armature can be considered from the commutator end, it will be noted that a clockwise rotation *A'* of the armature tends to turn the gear and wheels on the axle in a counter-clockwise direction *W'* and moves the car toward the south, or backwards, as indicated by arrow *C*.

In order to turn the rear axle so as to run the car forwards, or toward the north, the field-coil connection of the No. *2* motor should be reversed. The current now flows through the armature from brush *1'* to brush *2'* the same as before, but it enters coil *b'* and leaves coil *a'*, which reverses the polarity of the pole pieces, and as there is still a north pole at the top of the armature, the latter, seen from the commutator end, rotates in a counter-clockwise direction. This causes the rear axle to rotate in a clockwise direction; both motors are then forcing the car in the direction indicated by arrows *B*, or toward the north. The direction of rotation of the wheels and the No. *2* armature is indicated by the arrowheads on circles *W''* and *A''*.

Instead of reversing the direction of flow of the current through the No. *2* field coils, the direction of flow of the current through the No. *2* armature might have been reversed, leaving the direction of current in the field coils the same as in the case of the No. *1* motor. If this is done, the current enters the armature at brush *2''*, Fig. 17 (*b*), enters field coil *a''*, and leaves at the end of coil *b''*. The polarities of armature and pole pieces are indicated in Fig. 17 (*b*). The No. *2* armature rotation and the wheel rotation are indicated by *A''*, *W''* (seen from the commutator end), thus moving the car toward the north, as indicated by arrows *B*.

It should be noted in connection with this explanation that clockwise rotation of a wheel, when seen from one side, is counter-clockwise rotation when seen from the other side. The hands of a watch move over the upper portion of the dial from left to right. This is called clockwise rotation. If

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the hands of the watch could be seen from the back, they would appear to move over the upper part of the dial from right to left, or in a counter-clockwise direction. The actual rotation is the same, but in designating its direction, the point of view must be taken into consideration.

MOTORS USED AS BRAKES

GENERATOR ACTION OF MOTORS

25. Theoretical Considerations.—Under certain conditions, the car motors may be used for stopping a car in case of an emergency; the ability of the motors to act as dynamos enables them to perform this duty. In order that a motor may act as a dynamo, its field and armature connections must bear a certain relation to the direction in which the armature turns.

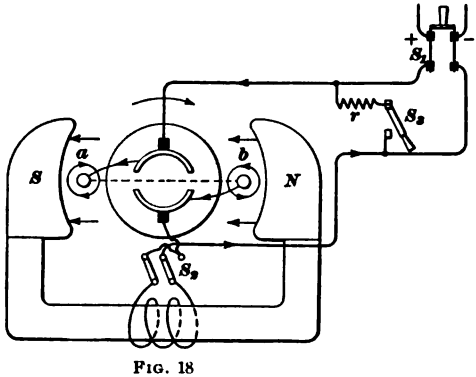

FIG. 18

The following explanation of the braking action of motors is based directly on the elementary discussion of motors and dynamos in the first portion of *Direct-Current Dynamos*. Fig. 18 shows a series motor connected by switch *S1* to a power line. The current flows through the simple armature winding, the reverse switch *S2*, and the field coil in the direction indicated by the arrowheads, giving the pole pieces the polarity shown. The interaction between the lines of force of the armature conductors and the field lines forces conductor *a* upwards and *b* downwards, which results in a clockwise rotation of the armature.

Now, consider that switch *S1*, Fig. 18, is open, that switch *S3* is closed, and that the armature of the motor is

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rotated by the application of some outside power in the same direction as before. The relative connections of armature and field remain unchanged. A resistance *r* is connected to switch *S3*. The residual magnetism of the pole pieces will be as indicated in Fig. 18. The machine is now trying to act as a generator. The conductors *a* and *b* are cutting across the field lines and have induced in them electromotive forces, which, in turn, cause a slight current to flow up in *a* and down in *b*. This direction of the current is just the reverse of the direction of the current flow when *a* and *b* were motor conductors, and the whirls of lines of force around the armature conductors would be as indicated in Fig. 19. There would be, then, in the conductors of Fig. 18 a denser field ahead of them than behind them, and it would require force to turn the armature against the magnetic forces that tend to rotate it in the opposite direction. With the connections as shown in Fig. 18, there would be but a slight temporary current, and the machine would not pick up as a generator. The current flows up in conductor *a*, Fig. 18, when acting as a generator conductor, out of the top brush, through *r* and *S3*, through the field coil in a counter-clockwise direction, when viewed from the left-hand side of the frame, and into the armature winding through the lower brush. The current flowing through the field coil tends to make the left-hand pole piece a north pole and the right-hand pole piece a south pole. This action destroys the residual magnetism in the pole pieces, thus bringing the magnetism down to practically zero value. The motor, with these connections and this direction of rotation, cannot, therefore, act as a generator.

26. In Fig. 19, the armature of the machine is rotated in the same direction as before, but the reverse switch *S2* is now at its right-hand position. The residual magnetism is as indicated by the letters *N* and *S*. The current flows through the circuit as indicated by the arrowheads. The current now enters the left-hand end of the field coil, circulates around it in a clockwise direction, when viewed

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from the left-hand side of the frame, and increases the strength of the north and south poles. If the armature is driven at a fairly high speed, the machine will pick up an electromotive force, thus acting as a generator, and current will flow through the closed circuit consisting of the resistance r, field coil, and armature. It is necessary that the machine run above a certain speed value, called the **critical speed**, in order to generate. This speed depends on the resistance in circuit. In the case under consideration it is low, permitting the machine to generate at low speed. The machine shown in Fig. 18 can be made to generate by reversing the field connections and keeping the direction of rotation and the armature connections the same, as just explained; by reversing the direction of rotation and keeping the armature and field connections the same; and also by reversing the armature connections and keeping the direction of rotation and the field connections the same.

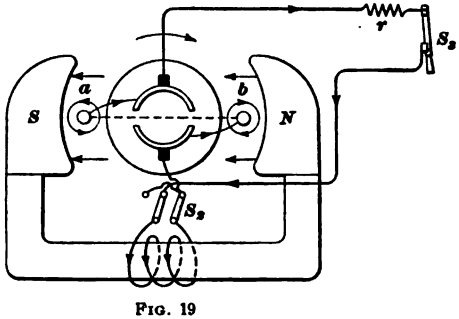

FIG. 19

27. In Fig. 20, two car motors are shown connected in parallel. Considering only the motor connections and the wires connecting the two motors, the motors may be said to be in series with each other. The overhead switch is supposed to be thrown out, the reverse switch thrown to its back position, the main controller drum turned to a parallel position, and the car moving forwards because of its momentum. The reverse switch being in the back position, the relative connections of armature and field coil and the direction of rotation are such that one or the other of the motors can act as a generator, as explained in connection with Fig. 19.

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Both motors tend to start generating and to set up electromotive forces that directly oppose each other; but one machine starts to pick up a little before the other, owing to the fact that the residual magnetism of one machine is usually a little stronger than that of the other. The stronger electromotive force overcomes the weaker electromotive force, and the first machine picks up as a generator and forces current through the other machine. This causes the second machine to act as a motor and tends to drive the car wheels connected to it in the opposite direction to that in which they are driven by the moving car.

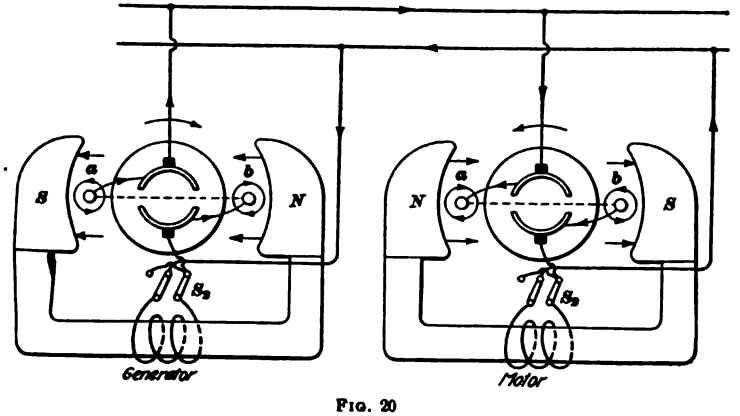

FIG. 20

In Fig. 20, the machine on the left is supposed to be the generator. The moving car is driving the generator armature in a clockwise direction. The armature and field connections are the same as those shown in Fig. 19. The current from the machine acting as a generator flows into the top brush of the motor and through the field coil in such a direction as to make a north pole on the left and a south pole on the right of the motor armature. Under these conditions, the tendency is to set up a counter-clockwise direction of rotation of the motor armature. This tends to turn the car wheels connected to the motor armature by gearing in the opposite direction to that caused by the forward movement of the car. There is little ohmic resistance in the circuit

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of the two motors, and a dangerously high current may result from this braking action. It takes power to drive the generator armature, and the motor also exerts a braking effort by trying to reverse the direction of motion of the car.

The momentum of the car is all that drives the generator armature. The dragging effect of the generator armature and the braking action due to the tendency toward reversed rotation of the car wheels connected to the motor armature soon overcomes the momentum of the car. As the speed decreases, the braking effect of the motors decreases because of the decreased electromotive force generated in the motor acting as a dynamo, so that if the car is on a down grade, the hand-brakes or air brakes must be applied; or, in case these are out of order, the wheels can be blocked and the car brought to a standstill in that way. The speed of the car is so greatly reduced by the action of the motors that the car can quite easily be brought to rest.

28. Backing Down Hill.—In case the car starts to run backwards down a hill and the motors are to be used as brakes, the overhead switch should be knocked off, the reverse switch left on its forward position, and the controller drum turned to a parallel position. As the car is running backwards, the rotation of the armatures is reversed, so that the armatures and field coils are properly connected to make the motors generate and set up braking action. In Fig. 18, open *S1*, close *S3*, reverse the rotation of the armature, and the armature and field-coil connections are correct for generator action. The current flows up in *b*, through the field coil in a clockwise direction, when viewed from the left-hand side of the frame, thus setting up the proper polarity, then through the resistance *r*, and into the armature at the top brush.

29. Precautions.—It is well to know how to use the motors as brakes in case a brake chain should snap and the line lose its power, thereby rendering both the brakes and reversing gear ineffective. It is not well, however, to make a practice of stopping a car in this way, for as the fuse or

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breaker is outside of the local circuit, consisting of the two motors and the reversing mechanism, the motors are not protected from overload. Again, the sudden reversing of the armature of the machine, acting as a motor, strains the pinion just as does regularly reversing, or "plugging," the car under headway.

In order to use the motors as brakes with a series-parallel controller, the overhead switch should be knocked off, the controller handle thrown to the off-position, the reverse handle thrown to the back position (if the car is moving forwards), and the controller drum then turned to the first parallel notch. There is then a local path through the motors, and the direction of rotation and the relative armature and field-coil connections are correct for braking action. In case the car is rolling backwards down a hill, and, because of lack of power on the line and disorder in the ordinary brake rigging, it is necessary to use the motors to brake the car, leave the reverse switch at the go-ahead position and advance the controller drum to the first parallel position. The rotation has been reversed by the car rolling backwards down the hill; therefore, the relative armature and field-coil connections do not have to be changed. If there is no power on the line, the overhead switch may be left on or knocked off, at will. If time permits, it may be opened, in order that the line current may not interfere with the generator action of the motors in case the power comes back on the line during the operation.

BUCKING OF MOTORS

30. Sometimes, a car under headway will receive a sudden check in its speed, producing much the same effect as an instantaneous application of a powerful brake; such action is called **bucking.** The bucking may be momentary, or it may be prolonged to the extent of bringing the car almost to a stop, unless a fuse or breaker acts. The action of the car depends on the nature of the cause of the bucking. It is generally caused by a short circuit.

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31. Armature Next to the Ground.—In many early equipments, the armature was connected next to the ground, as shown in Fig. 21. If a ground occurs between the field coil and the armature of one of the motors, the current flows through the field coil and then through the faulty ground connection to the motor frame and rail. The armature is short-circuited, and as the current through the field coil and faulty ground connection is not now opposed by the counter electromotive force of the motor armature, an excessive current flows through the field coil, causing a strong magnetic field to be set up. The armature is being rotated by the forward motion of the car, sustained by the good motor. The counter electromotive force of the armature now acts as a generator electromotive force, and sends current out from brush *a*, which was formerly the positive motor brush, through the faulty ground connection to *b*, to *c*, up through the permanent ground connection, and into the armature through brush *d*. The affected motor acts as a separately excited dynamo operating on a short circuit. The current through the armature is very large, and the dragging action, or bucking, is excessive. The armature is now a generator armature, and the magnetic attraction between the armature and field

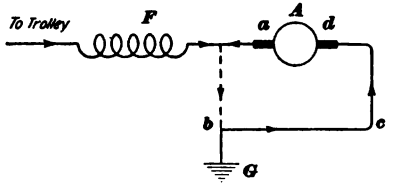

FIG. 21

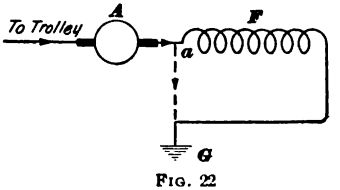

FIG. 22

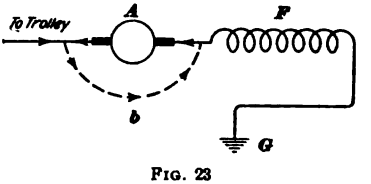

FIG. 23

is such as to tend to rotate the armature in a direction opposite to that in which the car is driving it.

The bucking action may be brought about by current flashing over from the positive brush holder to the frame, by a connection between the field coil and the frame, or by

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a ground connection on the wires connecting the field or armature.

32. Field Next to the Ground.—The present practice is to connect the field coils next to the ground. A single faulty ground, with the connections as shown in Fig. 22, does not admit of true bucking action. If a ground occurs at *a*, the field coil will be short-circuited, the counter electromotive force of the armature will be reduced, and an excessive current will flow through the armature and fault *a* to the ground. The car fuse or breaker will blow, but there is no generator action of the armature; therefore, there is no true bucking action.

In case the brush holders became short-circuited by a wire falling across them, as illustrated by the dotted line *b*, Fig. 23, bucking action would take place. The current would flow around the armature and through the field coil to ground. The electromotive force generated in the moving armature would force a large current through the local circuit *A* and *b*, and the car would be suddenly halted.

Another advantage of connecting the field coils next to the ground is that the counter electromotive force of the armature, which opposes the line electromotive force, allows only a small difference of potential to exist between any portion of the field windings and the grounded frame of the motor. With the field coil ahead of the armature, the difference of potential between the field-coil winding and the frame is high, and there is more danger of field-coil trouble owing to the breaking down of the insulation.

33. Short-Circuited Armature.—If some of the coils on an armature are short-circuited in such a manner as to form one or more local paths inside the armature windings, bucking will occur. The movement of the short-circuited coils in the magnetic field sets up in them an electromotive force, which, in turn, forces a current to flow through the local path. At different positions of the coils, different values of electromotive force are generated, and therefore the value of the current through the local path varies. The

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interaction between the field lines and the lines of force set up by the current in these coils tends to retard the rotation of the armature. As the current varies, the amount of retardation also varies and the car runs with a jerky motion.

34. In the foregoing discussion, it has been considered that true bucking is brought about only by the generator action of the moving armature. The term bucking is sometimes applied to the effect of any condition that causes a sudden halt in the car speed, as, for example, a ground between the trolley and the motor, which will deprive the motor of current and cause the car speed to be reduced; in such a case, however, there is no true bucking action.

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SINGLE-PHASE SPEED CONTROL

THE AUTOTRANSFORMER

1. The voltage used on the trolley wire of single-phase roads has not been limited to a single standard value, as with direct current, but is usually 3,300, 6,600, or 11,000. The motors are generally wound for a voltage of from 225 to 250, and the trolley voltage is reduced for use at the motors by means of an **autotransformer**, or a *compensator*, as it is also called, mounted on the car.

The autotransformer has one coil only, a portion of it serving the purpose of both a primary and a secondary

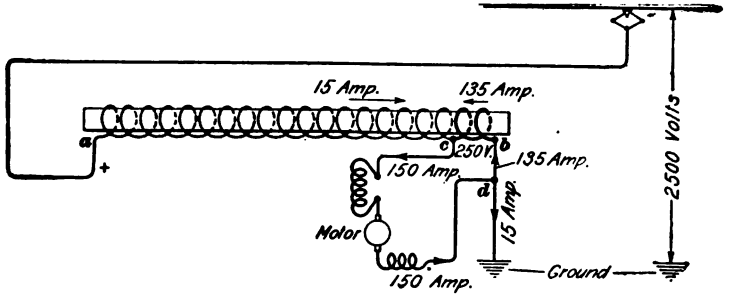

FIG. 1

winding. The coil is wound on a laminated-iron core, and taps are brought out at intervals, the primary and secondary circuits being connected to these taps.

2. The connections of an autotransformer arranged for a high-voltage primary and a low-voltage secondary are shown in Fig. 1. Terminal *a* is connected to the high-ten-

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sion trolley wire, and terminal *b* is connected to the ground. The secondary lines *c b* are connected across a section of the coil. The whole coil *a b* acts as a primary coil, and, in addition, the section *c b* of the primary acts as a secondary coil.

With a given primary electromotive force, the secondary electromotive force is directly proportional to the ratio of the number of secondary turns to the number of primary turns. For example, if the primary electromotive force is 2,500 volts, the secondary turns 2, and the primary turns 20, the secondary electromotive force is $2{,}500 \times \frac{2}{20} = 250$ volts. In an actual autotransformer for high voltage, the number of turns would be much greater than the number indicated in Fig. 1.

3. A motor requiring 150 amperes at 250 volts is connected to the secondary lines. The electromotive force of the primary circuit being ten times that of the secondary circuit, the current in the primary circuit, neglecting the transformation losses, is approximately one-tenth of that in the secondary circuit, or 15 amperes. The end *a* of the coil is assumed to be positive at a given instant. Point *c* is at a higher potential than *b*; therefore, current will flow from *c*, through the motor, and back to the coil at *b*. The 150 amperes flowing from *c* to the motor is made up of the 15-ampere primary current flowing in from the line to terminal *a* and 135 amperes from the secondary coil that is forced to flow through the coil from *b* to *c* by the electromotive force generated in the secondary coil. Not all the motor current is a transformed current; part of it is primary current. The autotransformer, therefore, for a given output, may be smaller than the ordinary two-coil transformer where the secondary current is entirely a transformed current. The current of 150 amperes flowing from the motor divides at *d*, 135 amperes flowing to *b* and through the secondary coil from *b* to *c*, and 15 amperes (primary current) flowing from *d* to the ground.

The current in the secondary coil is the difference between the current in the primary lines and that in the secondary lines. The current in section *a c* of the primary coil flows

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in a direction opposite to that in the secondary coil. The electromotive force applied to the secondary circuit may be varied by connecting the secondary terminals to different points on the primary winding. The portion of the coil that is used for the secondary of a step-down autotransformer is constructed of larger wire than the rest of the coil, as it must carry a larger current. If the autotransformer, Fig. 1, were to be used as a step-up transformer, the primary lines would have to be connected to *c b* and the secondary lines to *a b*.

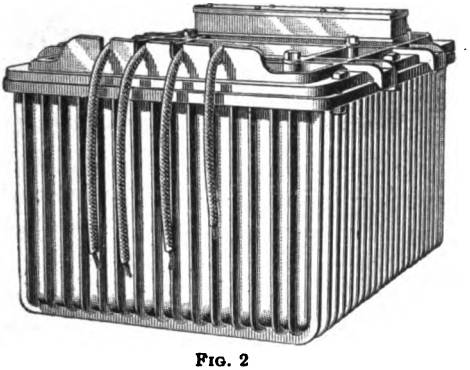

FIG. 2

4. In Fig. 2 is shown an **oil-insulated, self-cooling autotransformer** for use in connection with single-phase, alternating-current railway equipment. Fig. 3 illustrates the interior of the autotransformer. At *a* is shown a portion of the laminated shell core; at *b*, the coils; and at *c*, the leads.

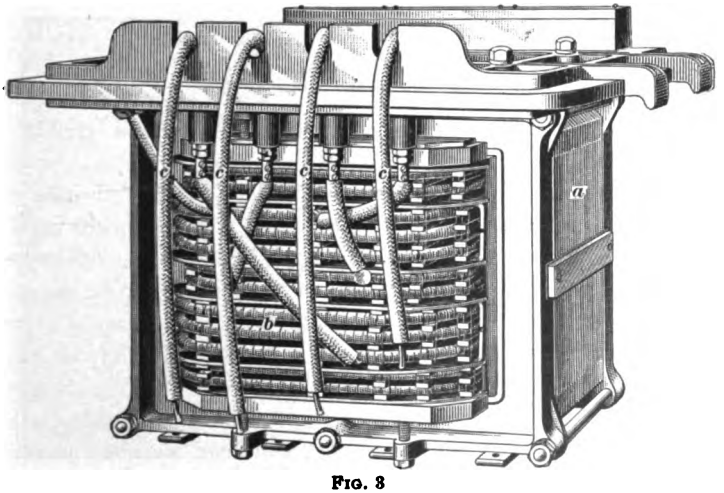

FIG. 3

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METHODS OF SPEED CONTROL

MOTOR AND AUTOTRANSFORMER CONNECTIONS

5. Speed control of the single-phase railway motor is obtained by varying the voltage at its terminals, the same as with direct-current motors. Where alternating current is used, however, this can be done much more easily and economically than with direct current. Instead of first connecting the motors in series and then in parallel and using a variable resistance in the circuit with each grouping, as is done with direct-current motors, it is merely necessary to connect the alternating-current motors to different steps on the autotransformer. This is accomplished in small equipments, where single-car operation only is desired, by means of drum-type controllers that are similar in general appearance to those used with direct-current motors. In large equipments, or where multiple-unit train operation is desired, essentially the same connections are made by means of unit switches operated by compressed air from the air-brake system and controlled by electromagnetic valves, or by means of electrically operated switches controlled directly from the master controller. The action of the magnet valves is regulated by a master controller, and current for operating them is supplied by a small 14-volt storage battery on the car.

Whenever a car equipment consists of only two motors, they are permanently connected in parallel, so that in case of damage to either motor, it may be cut out of circuit without interfering with the operation of the other. Where the equipment consists of four motors, however, they are usually connected two in series, and these two groups are connected in parallel. In case of damage to one motor of a four-motor equipment, the pair of motors to which it belongs is cut out. This arrangement is used to reduce the cost of controllers,

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switches, wiring, etc., which, within the limits ordinarily used, depends on the current to be handled rather than on the voltage. Thus, the same controller or switch group is used with a given size of motor, whether the equipment consists of two or four motors.

6. On some roads it is necessary to operate on direct current as well as on alternating current. The direct-current operation is generally through cities or towns, where the speed is necessarily limited, while the alternating-current operation is in the open country, where a high speed is

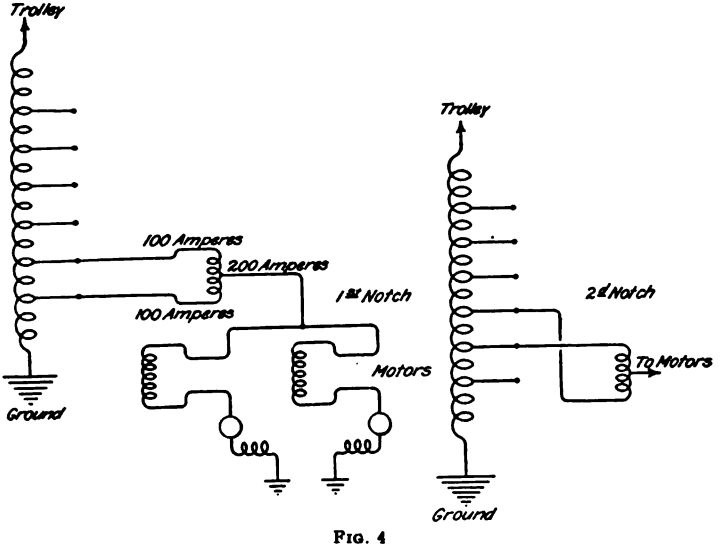

FIG. 4

usually desirable. The single-phase motor will operate somewhat faster on direct current than it will on alternating current of the same voltage. If, therefore, two 250-volt, alternating-current motors geared for the proper alternating-current speed are operated in series from a 500-volt, direct-current trolley system, the speed under these circumstances will usually be very much higher than is required. On this account, equipments for operation on both alternating and direct current are usually provided with four motors. These motors are operated two in series in the ordinary way on

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alternating current, but all four are connected in series on direct current. With this arrangement, the speed of a car with normal direct-current voltage on the trolley is about two-thirds of that with normal alternating-current voltage. When operating on direct current, the motors are controlled in the ordinary way by means of a resistance in series with them.

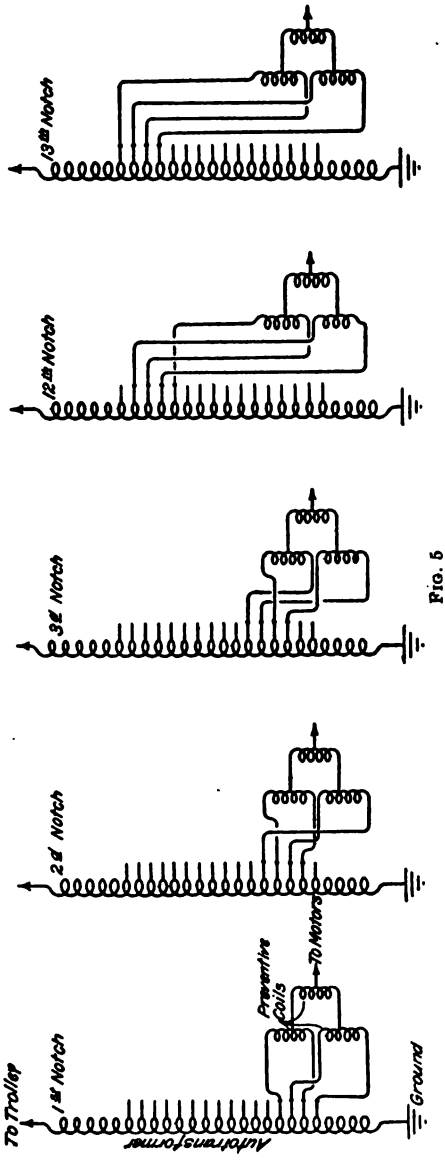

FIG. 5

7. In connecting the motors to the autotransformer, use is ordinarily made of one or more **preventive-reactance coils**, for dividing the current between two or more switches, or contacts. Thus, in Fig. 4, six taps and contacts, each of which is capable of carrying 100 amperes, will do the same work and provide for the same number of running points that would require five taps and contacts of double that size if the pre-

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ventive coil were not used. In Fig. 5, sixteen taps and contacts, each of which is capable of carrying 100 amperes, will do the same work that would otherwise require thirteen contacts of four times this capacity.

In addition to dividing the load among a number of small contacts, the use of the preventive-reactance coils serves also to prevent the necessity of opening the motor circuit when passing from one controller notch to the next, since in making this change only one lead is disconnected at a time. The two leads of a coil are so advanced that the former bottom lead becomes the upper lead as the coil is connected to the next higher-speed point. The reverse of this action takes place when the coil is connected to the next lower-speed point, as indicated in Figs. 4 and 5.

8. For use in connection with drum-type controllers, a **preventive resistance** is connected in parallel with the preventive-reactance coil, to reduce the sparking that may occur when breaking a tap contact. This arrangement of resistance and reactance coils is shown in connection with the following explanation of the type 224 controller. Each half of the preventive-reactance coil is bridged by one half of the resistance. When one of the tap contacts is broken, the current suddenly decreases in one half of the reactance coil. This would set up a high electromotive force of self-induction, and might cause sparking at the contact if it were not for the portion of the resistance through which the reactance coil may discharge, and thus allow the current and the magnetic field to decrease in strength slowly. In general, the action of this resistance is the same as that of the field discharge resistance ordinarily used in opening the field circuit of generators. The preventive resistance is so proportioned that there is very little loss in it, and in order to simplify the controller connections, it is left in circuit all the time, except on the last notch, where it can be cut out without adding complication. On account of the greater breaking capacity of unit switches, this resistance is not required where they are employed.

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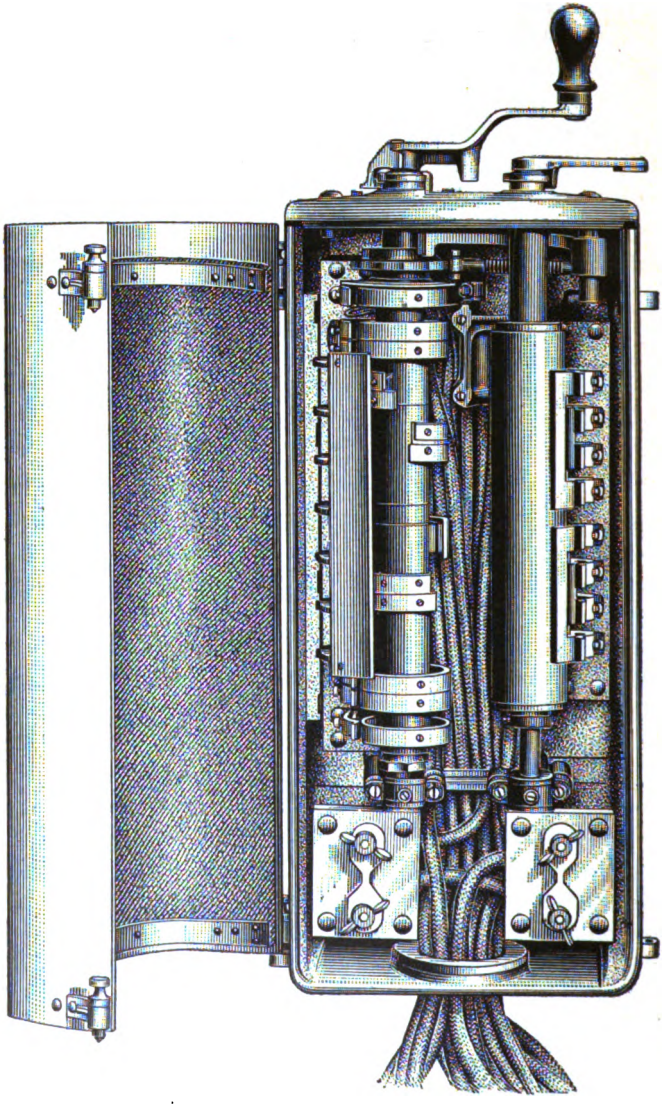

FIG. 6

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TYPE 224 WESTINGHOUSE CONTROLLER

DESCRIPTION OF CONTROLLER

9. In Fig 6 is shown a **type 224 Westinghouse controller** suitable for hand operation with two or four 50-horsepower, single-phase, alternating-current motors. In general appearance this controller is similar to a controller for direct-current operation. It contains a main power drum for connecting the various autotransformer taps to the motor circuit, and a reverse drum for reversing the direction of rotation of the motor armatures. Fig. 7

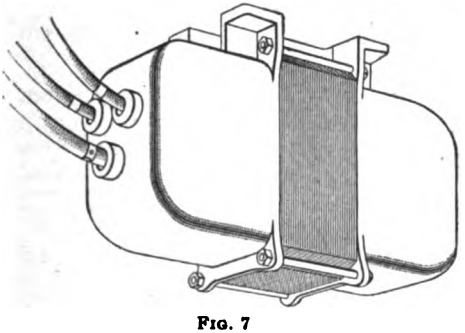

FIG. 7

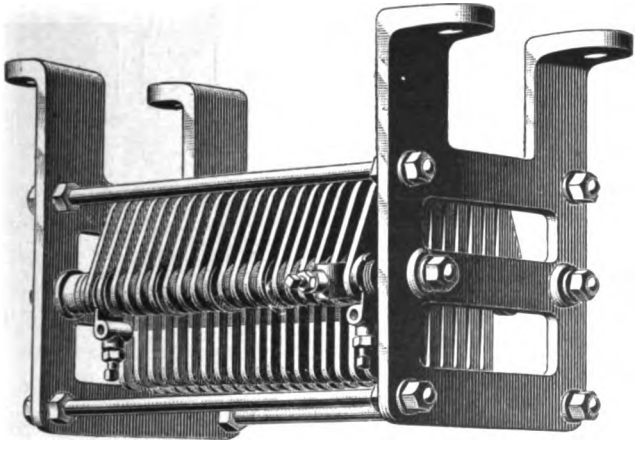

FIG. 8

shows the preventive-reactance coil, and Fig. 8, the preventive resistance, used in connection with the type 224 controller.

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CONTROLLER-WIRING DIAGRAM

10. In Fig. 9 is shown an autotransformer with six secondary taps and the wiring diagram of a type 224 hand controller arranged for connecting the several autotransformer taps to the motor circuit. The taps provide effective electromotive forces of 160, 190, 220, 250, 280, and 310 volts. The electromotive forces impressed on the motor terminals differ slightly from these values, owing to the action of the preventive coils.

The motor circuits receive current from the middle points of the preventive-reactance coil and the preventive resistance.

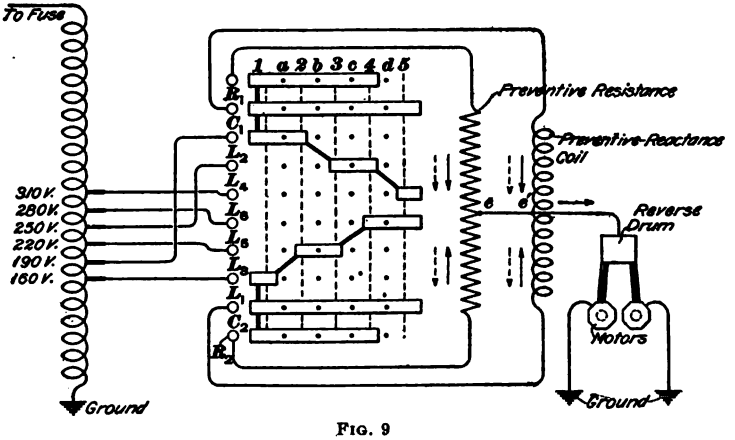

FIG. 9

The connections of the autotransformer, the preventive resistance, the preventive-reactance coil, the reverse drum, and the motors are shown diagrammatically in Fig. 10 for the five running notches. When the controller, Fig. 9, is on the *first notch*, as indicated by the dotted line under *1*, near the top of the controller, fingers *R1* and *C1* are connected with *L2* (the 190-volt tap), and fingers *C2* and *R2* are connected with *L1* (the 160-volt tap). As *R1* and *R2* are the terminals of the preventive resistance, and *C1* and *C2* are the terminals of the preventive-reactance coil, the electromotive force impressed on the coils is 190 volts − 160 volts = 30 volts, and the electromotive force at the middle points *e*

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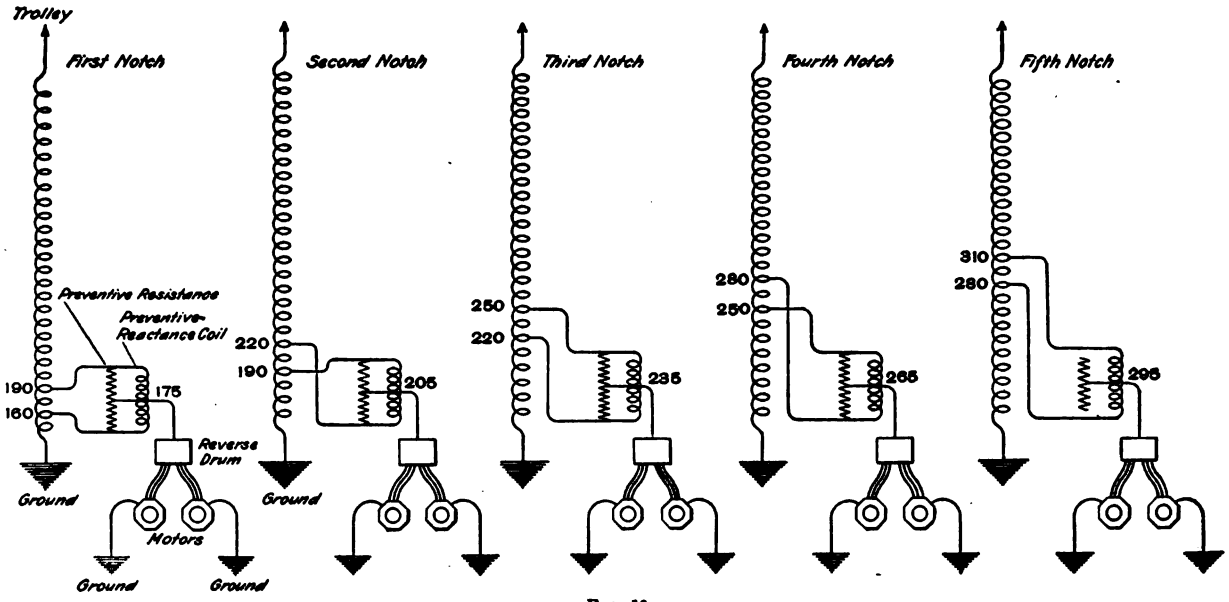

FIG. 10

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and e' of the coils is 15 volts higher than the lower value and 15 volts lower than the higher value, or 175 volts. The electromotive force of 30 volts forces currents through the resistance and the reactance coil independent of the operation of the motors. The directions of these currents are from the tap that is at a given instant of a higher potential to the tap that, at the same instant, is of a lower potential. The current therefore alternates through the coils.

11. First Notch.—If, in Fig. 9, the trolley wire is positive at a certain instant and the controller is on notch *1*, *L2* is at a higher potential than *L1*, and the electromotive force of 30 volts tends to send currents through the preventive coils in the directions indicated by the dotted arrows. If the motor circuit is also active, the currents from *L2* and *L1* flow to e and e' through the coils in the direction indicated by the full-line arrows. The motor currents in each half of a coil are in opposite directions and of nearly equal value. The currents join at the middle points of the coils and flow to the motor circuit. Where the normal exciting current of a coil and the motor current oppose each other, the motor current predominates and determines the direction of flow. At the particular instant under discussion, motor currents flow from the 190-volt tap *L2* to e and e', and from the 160-volt tap *L1* to e and e', there being an electromotive force of approximately 175 volts impressed on the motor circuit.

When the controller is passing from the first to the second notch, finger *L1* drops contact with its drum segment while finger *L2* still remains in contact with its drum segment. Current then flows through the upper portions only of the preventive coils and to the motor circuit from the 190-volt tap. The intermediate positions of the fingers are indicated by the dots under the letters *a*, *b*, *c*, and *d*.

12. Second Notch.—On notch *2*, *R2* and *C2* are connected with *L3* (the 220-volt tap), and *R1* and *C1* are still connected with *L2* (the 190-volt tap). The impressed electromotive force on the motor circuit is now 205 volts.

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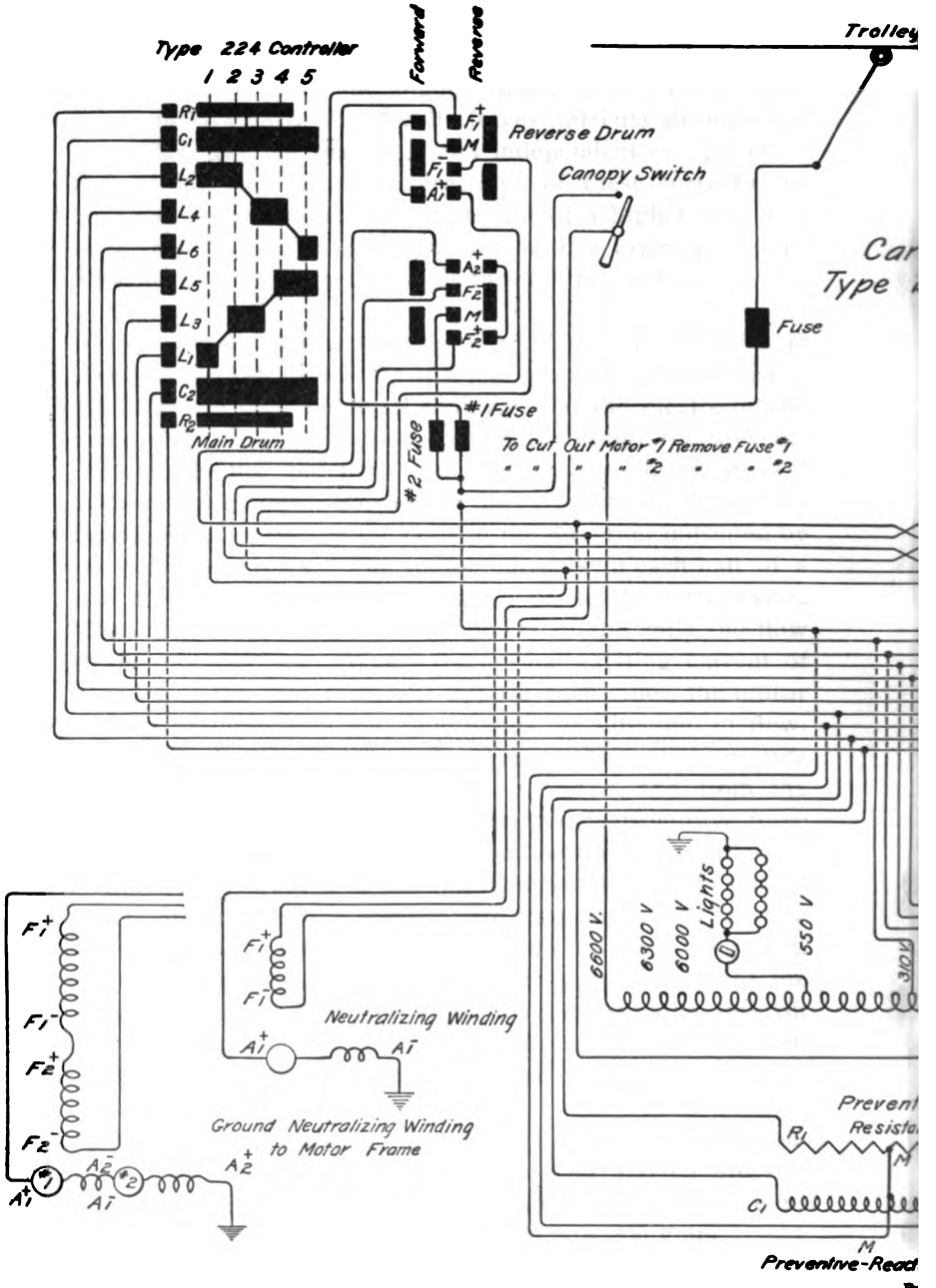

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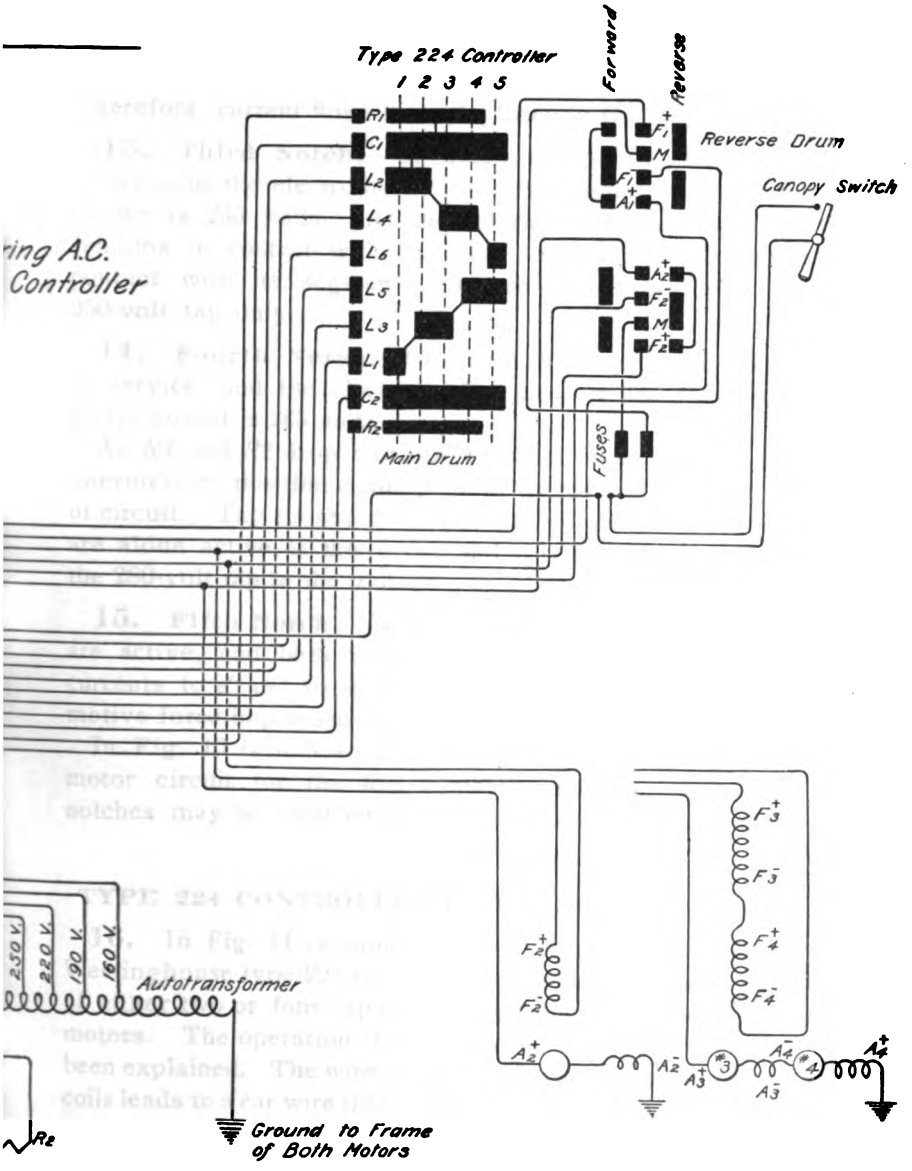

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At the intermediate position *b*, *L3* remains in contact with its drum segment, but *L2* drops contact with its segment. Therefore, current flows from the 220-volt tap only.

13. Third Notch.—On notch *3*, taps *L4* and *L3* are active, and the electromotive force impressed on the motor circuit is 235 volts. At the intermediate position *c*, *L4* remains in contact with its drum segment, but *L3* drops contact with its segment. Current now flows from the 250-volt tap only.

14. Fourth Notch.—On notch *4*, taps *L5* and *L4* are in service, and the electromotive force impressed on the motor circuit is 265 volts.

As *R1* and *R2* drop contacts with their drum segments at intermediate position *d*, the preventive resistance is cut out of circuit. Tap *L5* and the lower half of the reactance coil are alone active at this point, and current now flows from the 280-volt tap to the motors.

15. Fifth Notch.—At the final notch *5*, taps *L6* and *L5* are active, and both sections of the reactance coil carry currents to *e'* and to the motor circuit. The final electromotive force impressed on the motor circuit is 295 volts.

In Fig. 10 is indicated the voltage of the taps and the motor circuit for the five controller notches. All these notches may be used efficiently for running, if so desired.

TYPE 224 CONTROLLER CAR-WIRING DIAGRAM

16. In Fig. 11 is shown a car-wiring diagram for two Westinghouse type 224 controllers suitable for the operation of either two or four type 108, single-phase, 50-horsepower motors. The operation of the main controller drum has just been explained. The wire from the middle of the preventive coils leads to a car wire that connects to two fingers marked *M* on the reverse drum of each controller. The two motors are permanently connected in parallel. The upper half of the reverse drum controls motor No. *1*, and the lower half controls motor No. *2*.

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When the reverse drum is thrown from one position to the other, the field terminals are interchanged, while the armature terminals remain unchanged; this reverses the direction of rotation of the motors. The armatures and the neutralizing windings in series with them are grounded on the frames of the motors.

If four motors are to be used, motors Nos. *1* and *2* are connected permanently in series, as indicated by the small sketch at the left in Fig. 11, and are considered as one unit, so far as the controller connections are concerned. Motors Nos. *3* and *4* are also connected in series, as shown by the sketch at the right in Fig. 11, and are considered as one unit. The two pair of motors thus formed are connected in multiple.

LATER TYPE 224 CONTROLLER CAR-WIRING DIAGRAM

17. A later type of 224 controller is indicated in the car-wiring diagram shown in Fig. 12. In this controller the contacts on the power drum are so arranged that one side of the preventive-reactance coil and one side of the preventive-resistance grid are connected to the transformer tap *L1* before the other sides of the preventive coils are connected to the transformer tap *L2*. When starting, the low electromotive force due to the first transformer tap alone is first impressed on the motor circuit. The connections are shown for four motors, and some of the reverse-switch connections are altered. The operation of the controller is, however, practically the same as stated in the preceding explanation.

TYPE 455 CONTROLLER CAR-WIRING DIAGRAM

18. In Fig. 13 is shown a car-wiring diagram for two **Westinghouse type 455 hand controllers** that are designed for controlling a four-motor equipment of four 50-horsepower motors on either an alternating- or a direct-current system. When operating on alternating current, the

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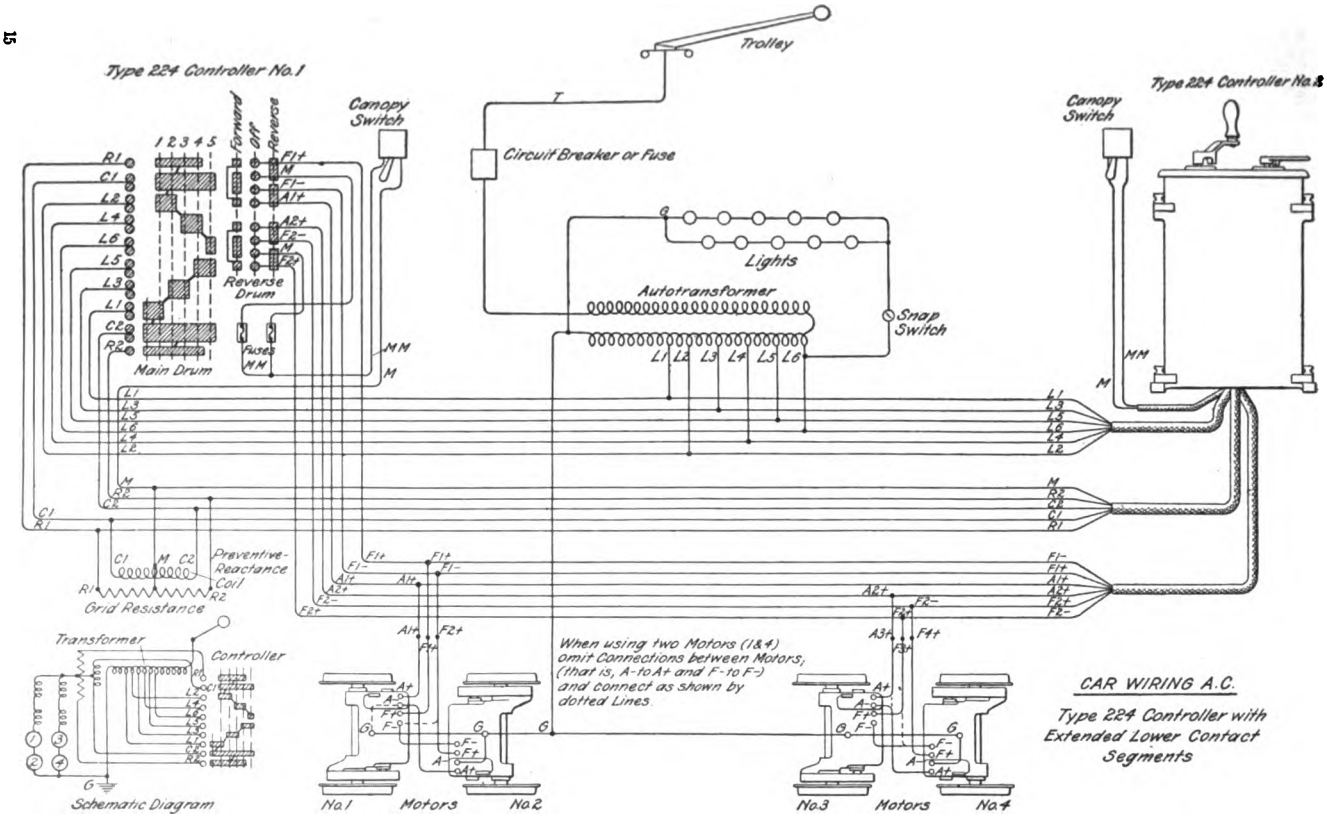

FIG. 12

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pantagraph trolley is ordinarily used. This is controlled by means of an air valve in the motorman's compartment. When operating on direct current, either one of the wheel trolleys is used, according to the direction in which the car is running. The wheel trolleys are mounted on insulated bases, and an oil-insulated emergency switch is connected so that, in case of accident to the pantagraph trolley, throwing this emergency switch to the alternating-current position will permit either wheel trolley to be used on alternating current, and will thus enable the car to be brought back to the barn.

A canopy switch is used on each end of the car to enable power to be cut off in case the controller, for any reason, should stick on the on-position. Under such circumstances, opening the canopy switch will cut off power from the car and thus enable it to be stopped.

Each controller contains a direct-current drum, two alternating-current drums, a reverse switch, and cut-out switches. Resistances *R1* to *R5* and the upper portion of the direct-current drum are used in connection with motors Nos. *1* and *2*. Resistances *R6* to *R10* and the lower portion of the direct-current drum are used in connection with motors Nos. *3* and *4*. The two alternating-current drums are geared together, so that while one is turning in one direction the other is moving in the opposite direction. The left-hand drum controls motors Nos. *1* and *2*, and the right-hand drum controls motors Nos. *3* and *4*. The car wires are marked by letters and figures. When direct current is to be used, one of the direct-current trolleys is placed on the wire and the emergency switch is thrown to its direct-current position. When alternating current is to be used, the alternating-current pantagraph trolley is placed on the wire, and the direct-current trolley is hauled down.

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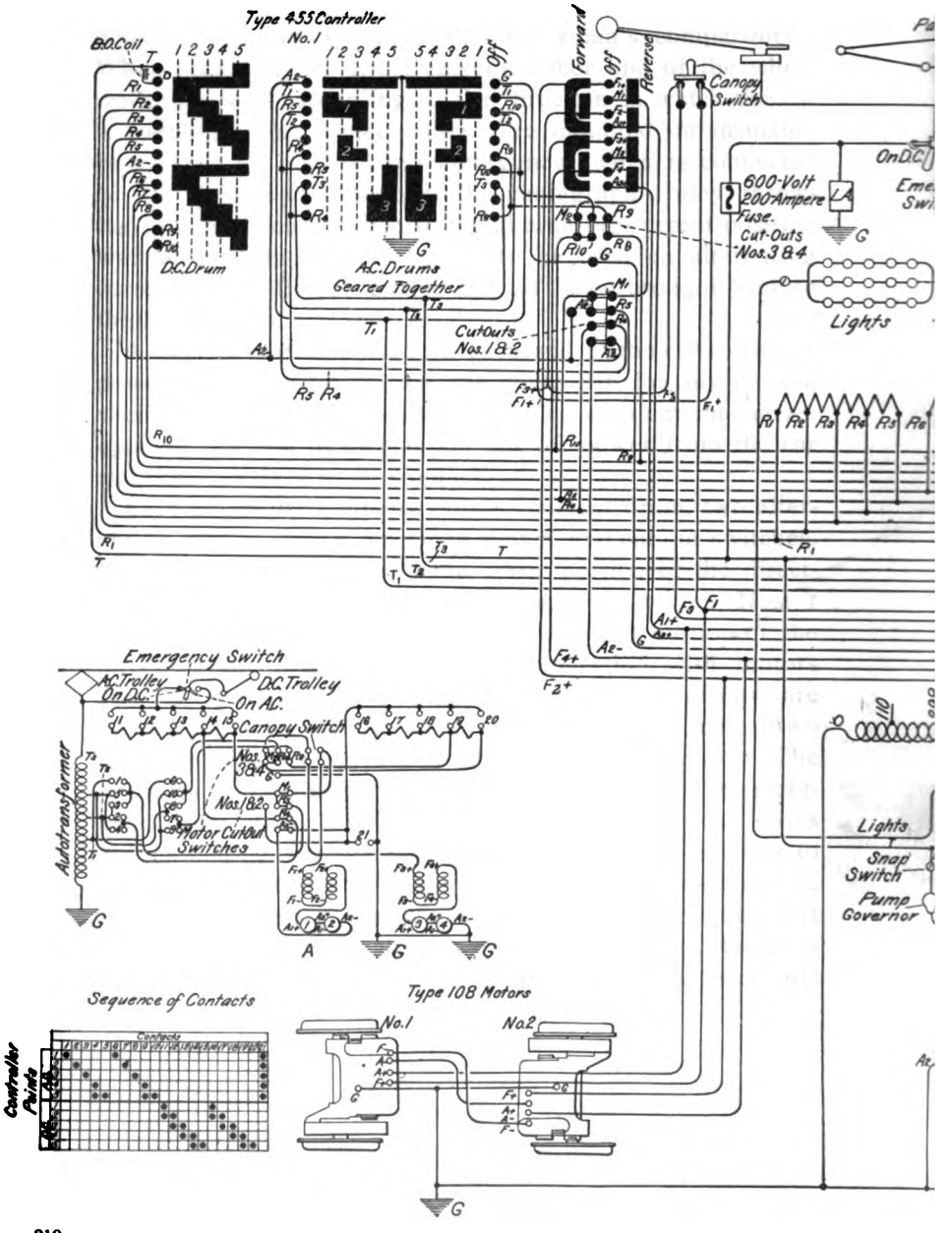

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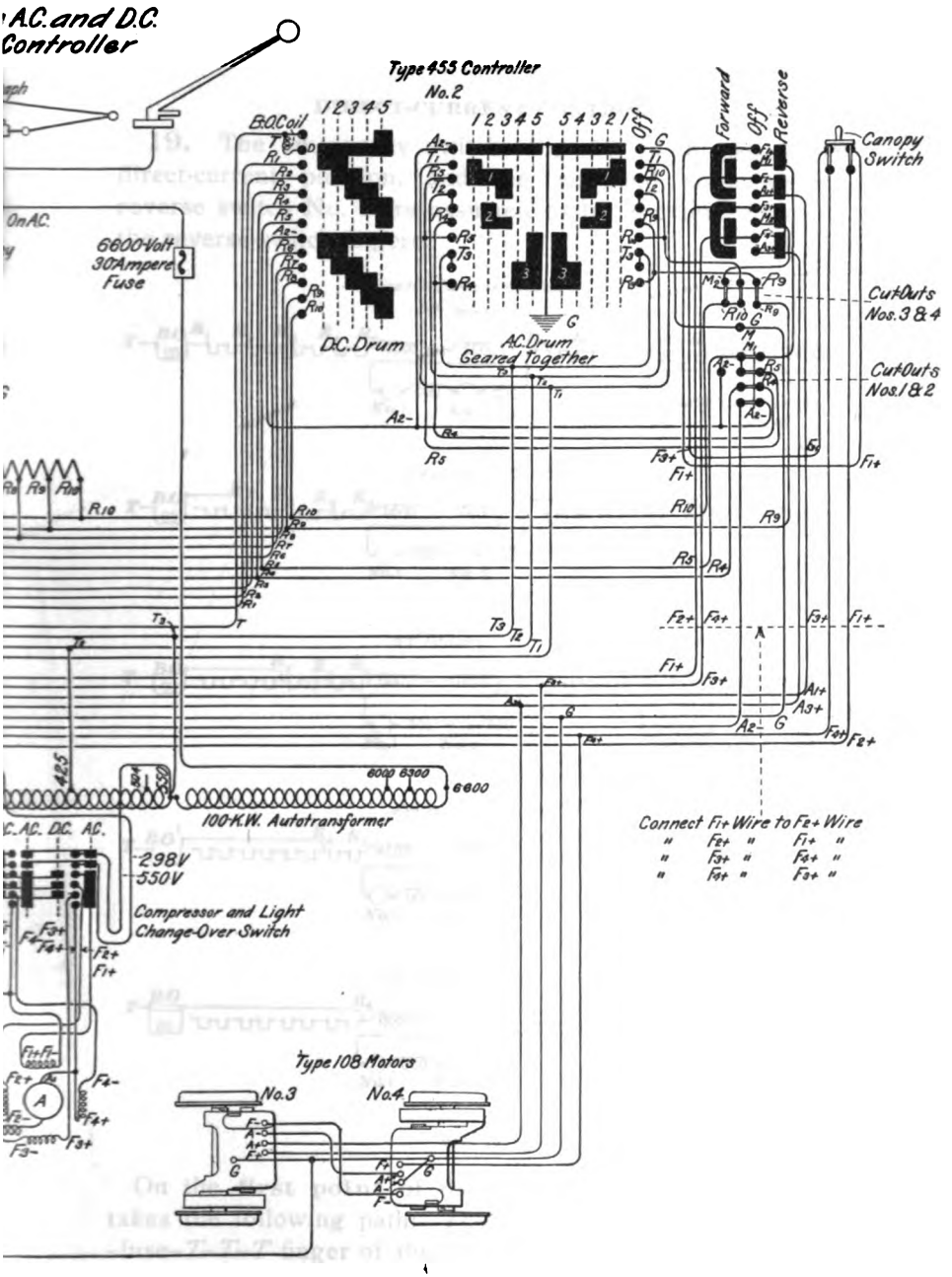

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DIRECT-CURRENT CONTROL

19. The emergency switch, Fig. 13, is thrown to its direct-current position, and the left-hand segments of reverse switch No. *1* are assumed to be in connection with the reverse-switch fingers.

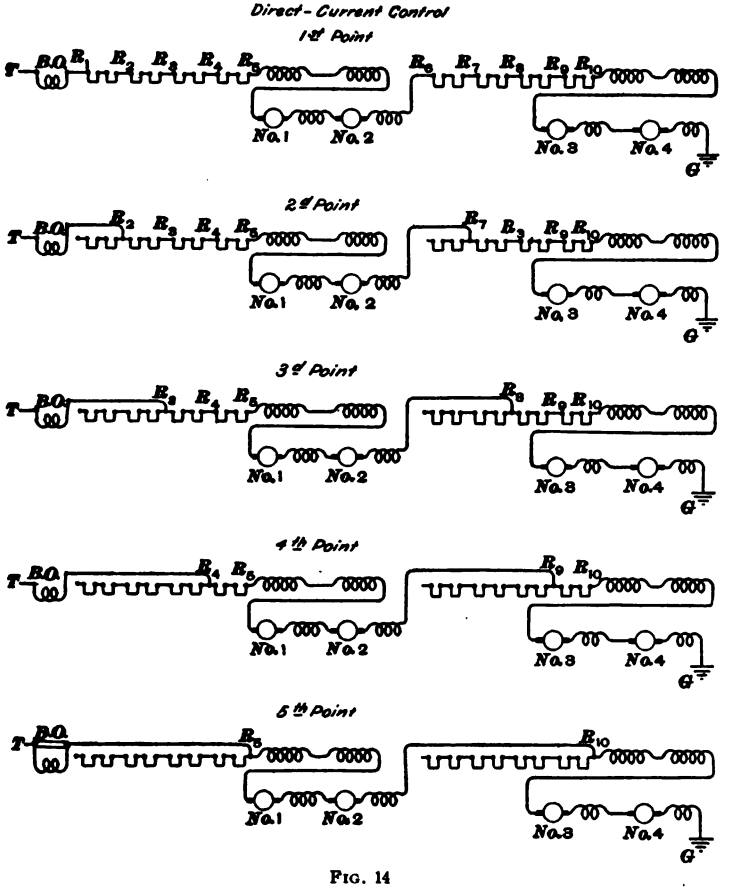

FIG. 14

On the **first point** of the direct-current drum, current takes the following path: *D.-C.* trolley–emergency switch –fuse–*T*–*T*–*T* finger of the *D.-C.* drum–*B.-O.* coil–*D* finger–

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drum segment–*R1*–*R1*–*R1*–resistances between *R1* and *R5* –*R5*–*M1* cut-out switch–*M1* reverse switch–*F2*– –*F2*+ –*F*+ –through field of No. *2* motor–*F*– –*F*– –through field of No. *1* motor–*F*+ –*F1*–canopy switch–*F1*+ –*F1*+ –*F1*+ –*A1*+ –*A1*+ –*A*+ –through armature of No. *1* motor–*A*– –*A*+ –through armature of No. *2* motor–*A*– –*A2*– –*A2*– –*A2*– –finger *A2*– –*D.-C.* drum segment–*R6*–*R6*–resistances–*R10* –*R10*–*R10*–*R10*–*M2*–*F4*– –*F4*+ –*F4*+ –*F*+ –through field of No. *4* motor–*F*– –*F*– –through field of No. *3* motor–*F*+ –*F3*+ –*F3*–canopy switch–*F3*+ –*F3*+ –*F3*+ –*A3*+ –*A3*+ –*A3*+ –*A*+ –through armature of No. *3* motor –*A*– –*A*+ –through armature of No. *4* motor–*A*– –*G* on motor frame. The four motors and all the resistance sections are in series.

20. The connections of the motors on the first point, as well as those on the four following points, are shown diagrammatically in Fig. 14. On the second point, Fig. 13, the sections of resistance between *R1* and *R2* and *R6* and *R7* are cut out. On the third point, two more sections are cut out. On the fourth point, two sections are cut out. On the fifth point, the last two sections are cut out and the blow-out coil is short-circuited, thus leaving the four motors in series across the line.

ALTERNATING-CURRENT CONTROL

21. The pantagraph trolley, Fig. 13, is placed in operation, and the direct-current trolley is hauled down. The reverse switch is assumed to be in the same position as before, and the two alternating-current drums on controller No. *1* are operated. Current flows from the trolley wire through the alternating-current fuse and autotransformer to the ground. The lowest voltage tap is *T1*, the next higher *T2*, and the highest *T3*.

22. On the **first point**, the current flows from tap *T1* to *T1*, and to junction *T1* under the alternating-current drums. Part of the current flows to finger *T1* of the right-hand drum, and part to finger *T1* of the left-hand drum.

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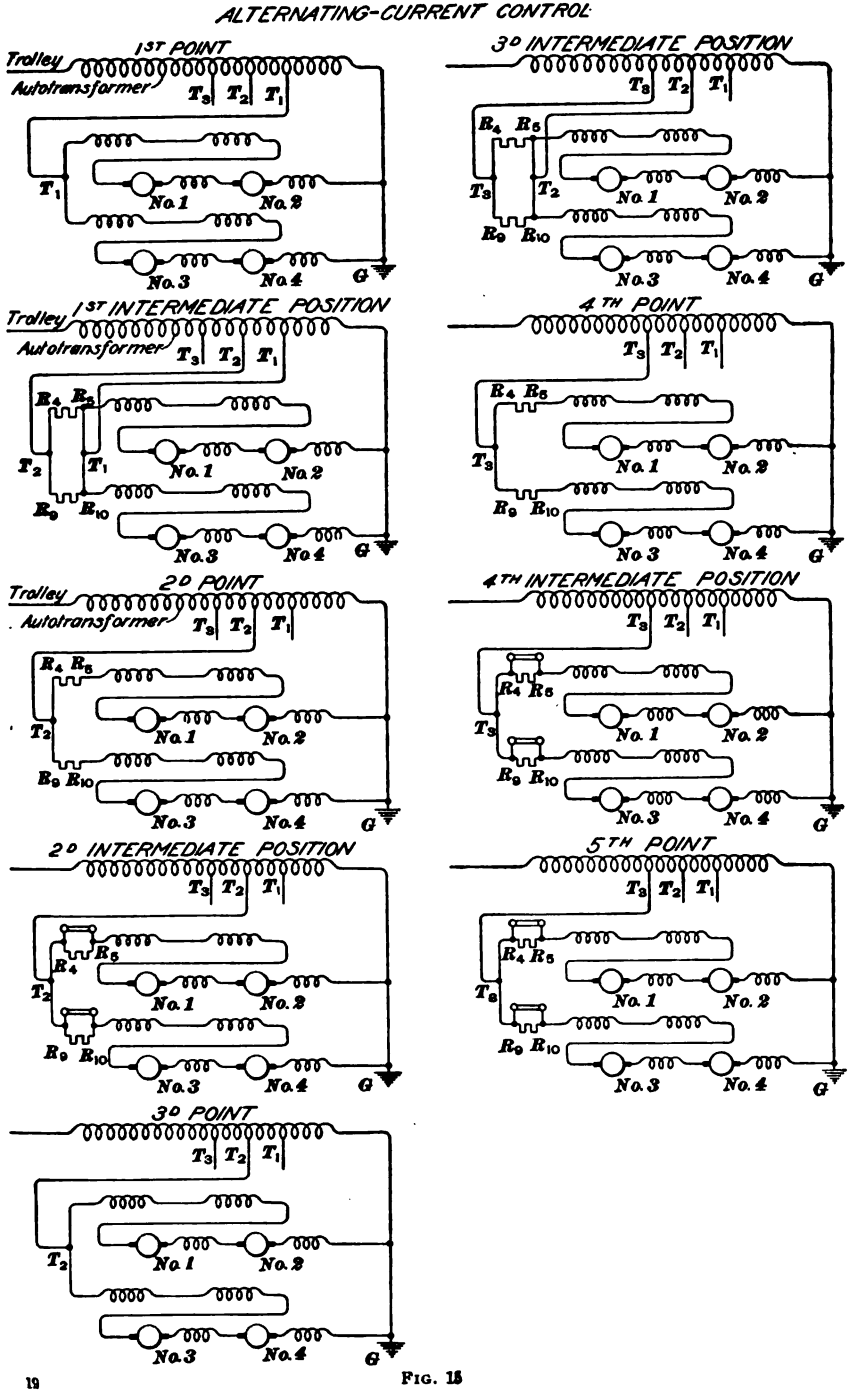

FIG. 15

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Considering the left-hand drum, the path of the current is as follows: Finger *T1–R5–R5–R5–M1–M1–F2*— *–F2+ –F+ –F– –F– –F+ –F1*–canopy switch–*F1+ –F1+ –F1+ –A1+ –A1+ –A+ –A– –A+ –A– –A2– –A2– –A2– –A2–* finger on *A.-C.* drum–top drum segment to ground. Motors Nos. *1* and *2* are in series between tap *T1* and the ground connection.

By the action of the right-hand drum, motors Nos. *3* and *4*, which are permanently in series, are connected between tap *T1* and the ground. The two sets of motors are in parallel. This is shown diagrammatically in Fig. 15 at the first alternating-current point.

When moving to the **first intermediate position,** finger *T1*, Fig. 13, does not leave contact with its drum segment until the lower finger *T2*, which is connected to tap *T2*, makes contact with its drum segment. At this intermediate position, on either of the two drums, a section of resistance is shunted between fingers *T1* and *T2*, and immediately afterwards finger *T1* loses its contact and the resistance is left in series with tap *T2*. Suppose that finger *T1* on the left-hand drum is touching the top of segment *1*, and that the lower finger *T2* is touching the top of segment *2*; there is then a path from the higher voltage finger *T2* to finger *T1* as follows: Lower finger *T2*–drum segment *2–R4–R4–R4–R4–R4*–one resistance section *–R5–R5–R5–R5*–finger *R5*–drum segment *1*–finger *T1*. The section of resistance between *R4* and *R5* acts as a shunt on one drum, and the section of resistance between *R9* and *R10* serves the same purpose on the other drum. The two sections of resistances are thus in parallel between taps *T1* and *T2*, as indicated at the first intermediate position, Fig. 15.

23. When the drums, Fig. 13, are turned to the **second point,** fingers *T1* lose contact with segments *1*, and a resistance section is left in series with each set of motors, as shown in Fig. 15 at the second point. Tap *T1* is cut out and tap *T2* remains active.

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On the **second intermediate position,** finger *T2*, Fig. 13, makes contact with segment *1*. Current can now flow from *T2*–segment *1*–*R5*–*R5*–*R5*–*M1*–*M1*–*F2*–*F2*+ and through motors Nos. *1* and *2*. Upper finger *T2* touches segment *1*, and lower finger *T2* touches segment *2*, thus short-circuiting the resistance section between *R4* and *R5*, as shown at the second intermediate position, Fig. 15. Similar action takes place on the other alternating-current drum.

24. On the **third point,** lower finger *T2*, Fig. 13, drops contact with segment *2*, and upper finger *T2* remains in contact with segment *1*. The two sets of motors are connected between tap *T2* and the ground, as shown in Fig. 15, third point.

When the **third intermediate position** is reached, lower finger *T3*, Fig. 13, touches segment *3*, and upper finger *T2* touches segment *1*. Taps *T3* and *T2* are shunted by one resistance section on each drum. The resistance section between *R4* and *R5* is connected between lower finger *T3* and upper finger *T2*, on the left-hand drum, and the resistance section between *R9* and *R10* is connected between the corresponding fingers on the right-hand drum. On this position, finger *T3* is in contact through segment *3* with *R4*, and finger *T2* is in contact through segment *1* with *R5*. The motor connections are shown at the third intermediate position, Fig. 15.

25. On the **fourth point,** fingers *T2* and *R5*, Fig. 13, drop contact with segment *1*. A resistance section is left in series with each set of motors, as shown in Fig. 15, fourth point.

When the **fourth intermediate position** is reached, finger *R5*, Fig. 13, makes contact with segment *3*, and as fingers *R5* and *R4* are now in contact with the same segment, the resistance section connected to each drum is short-circuited. The motor connections are shown at the fourth intermediate position, Fig. 15.

26. On the **fifth point,** Fig. 13, the conditions are the same as on the fourth intermediate position. The resistances

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are short-circuited, and the sets of motors are connected in parallel between the high-voltage tap *T3* and the ground.

27. The pump motor for operating on either alternating current or direct current is arranged so that it operates with all the field coils in series on direct current, and all in parallel on alternating current. A change-over switch is used for varying these connections. The same switch also connects the lighting circuit to the transformer when the car is on alternating current, or to the wheel trolley when it is on direct current. When the car is on direct current, the change-over switch is thrown so that the direct-current segments are in contact with the fingers. On alternating-current operation, the alternating-current segments are in contact with the fingers.

28. The small sketch at the left in Fig. 13 shows diagrammatically the contacts that are necessary for the operation of the controller. The order in which the contacts are opened and closed on the different controller points is indicated by the tabular arrangement of sequence of contacts.

WESTINGHOUSE UNIT-SWITCH, ALTERNATING-CURRENT CONTROL

TYPE 334-A CONTROLLER

29. The controlling apparatus used with the Westinghouse unit-switch, alternating-current control system is, in general, similar to that employed in the Westinghouse unit-switch control systems arranged for direct-current motors. A small storage battery furnishes the direct current for the control circuits in both systems.

In Fig. 16 is shown a **type 334-A master controller,** and in Fig. 17, a car-wiring diagram for a type 255-F switch group and two 100-horsepower motors. For a four-motor equipment of the same size of motors, operating on a 3,300-volt circuit, the connections would be essentially the

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same. In the latter case, however, the motors would be connected two in series. With a four-motor equipment of

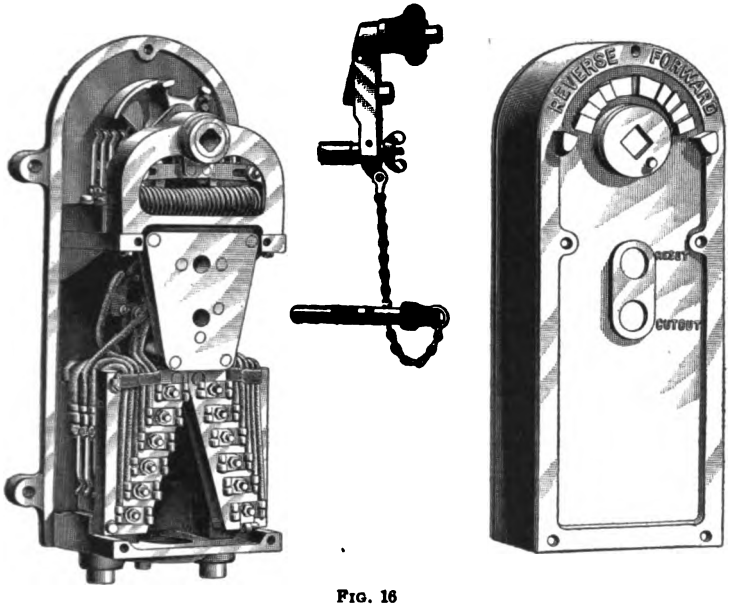

FIG. 16

such motors, on a 6,600-volt circuit, a circuit-breaker would be used in the high-tension circuit instead of a fuse.

TYPE ALTERNATING-CURRENT UNIT-SWITCH CONTROL. CAR-WIRING DIAGRAM, SCHEDULE M

30. Operation of the Trolley.—The pantagraph type of trolley is indicated in Fig. 17. The trolley is raised into contact with the trolley wire by springs and is lowered by air pressure, both movements being controlled by magnets and air valves. The storage-battery switch is closed so that either one battery or the other is connected to the control circuit. To raise the trolley, the plug shown in Fig. 16 is inserted into the reset receptacle on controller No. *1*, Fig. 17, thus joining contacts $B+$ and *6*. Starting from the positive battery terminal $B+$, the current path is as follows: $B+$ –knife switch–$B+$ –$B+$ –$B+$ –$B+$ –$B+$ –$B+$ –$B+$ –$B+$ –

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B+ –*B*+ –plug in reset receptacle–*6*–*6*–*6*–*6*–*6*–*6*–*6*–*6*–*6*–*6*–right-hand control magnet under the pantagraph trolley–*91*–*91*–*91*–*91*–*91*–*91*–interlock *A1* of switch *11* on switch group–*93*–*93*–*93*–*93*–interlock *A1* of switch *9*–*B*– –*B*– –negative battery wire, back to the negative terminal of the battery. The right-hand trolley control magnet is energized, admitting air to the trolley unlock cylinder; this releases the latch that holds the trolley in its lower position and allows powerful springs to raise the trolley to its active position.

To lower the trolley, the controller plug, which has two metal portions insulated from each other, is inserted into the cut-out receptacle, thus connecting together the upper cut-out receptacle contacts *B*+, *8A*, and *10A*, and also the lower cut-out receptacle contacts *3* and *3A*. The right-hand button, shown near the base of the controller in Fig. 16 and indicated in Fig. 17, is then pressed. The button temporarily raises the trolley segments so that fingers *10A* and *0* are connected. Starting from the upper cut-out receptacle contact *B*+ on the controller, the path is: *B*+ –plug–contact *10A*–finger *10A*–trolley segment–finger *0*–wire *0*, through junction boxes to the left-hand control, or valve, magnet under the pantagraph trolley–wire *B*–, to negative terminal of the battery. The control magnet admits air to the trolley and forces it to its lower position, where it is locked.

All the trolleys on the train may be operated from any one of the master controllers through the interconnecting control wires on the cars.

31. First Notch.—When controller No. *1*, Fig. 17, is to be operated, the controller plug is inserted into the cut-out receptacle. Since the button on the controller base is not pressed, the trolley control circuit is inactive. One of the metal portions of the plug connects receptacle contacts *3* and *3A*. In order to obtain forward movement of the car, the controller handle is moved toward the right. On the first forward notch, drum finger *B*+ is connected through one of the drum segments, all of which are electrically connected, to finger *1*. The path is: finger *B*+ –finger *1*–junction boxes

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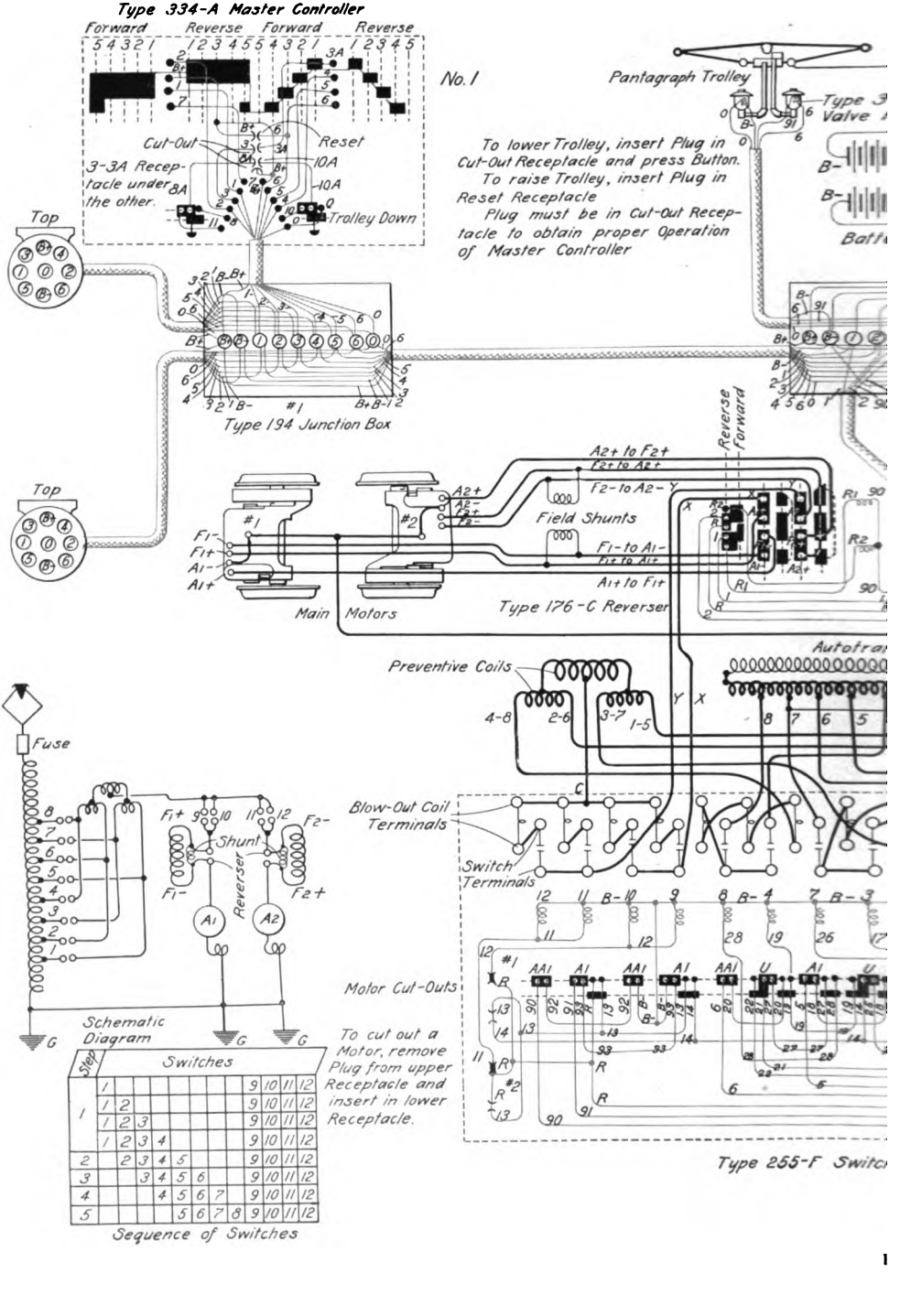

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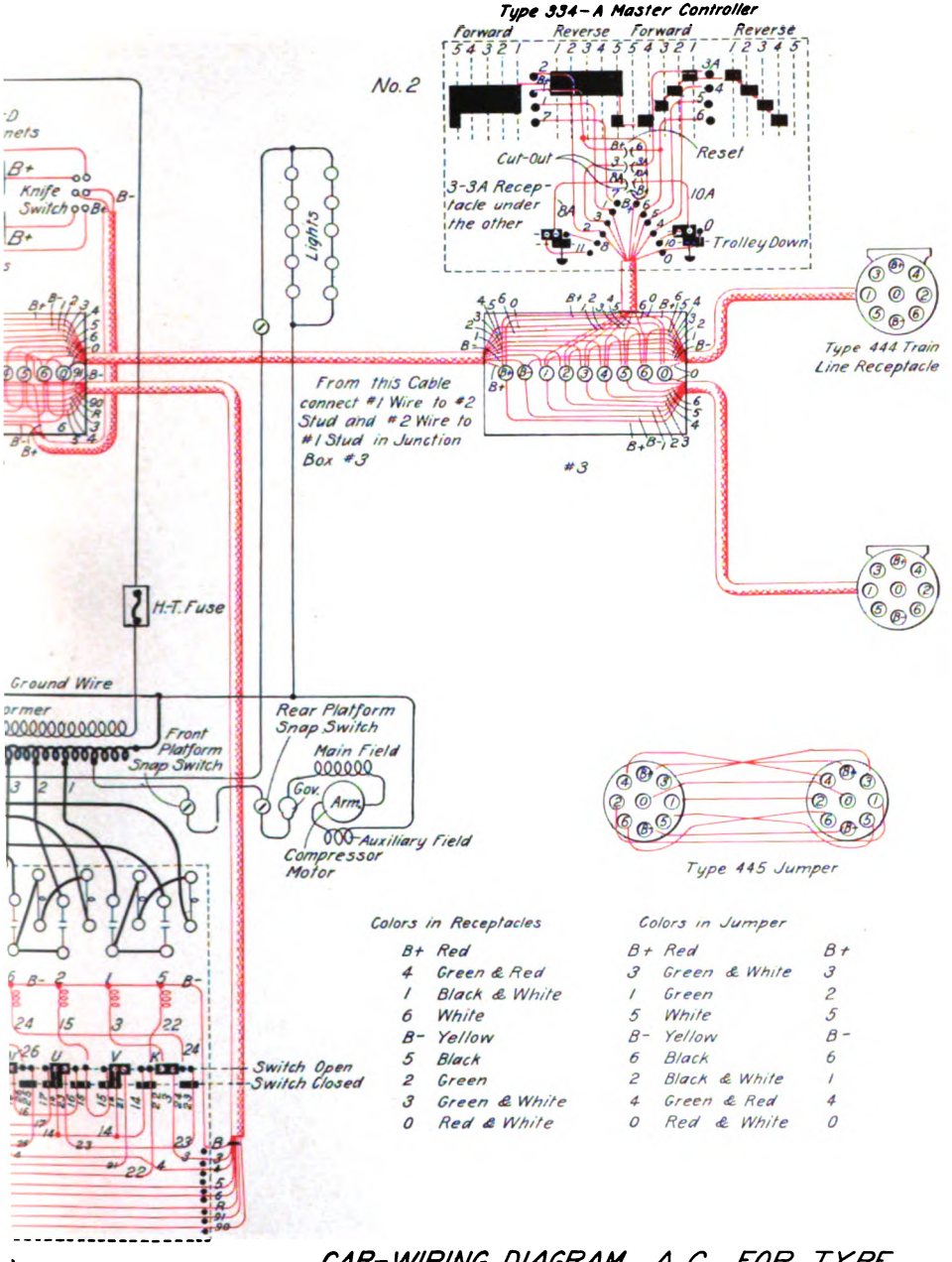

Colors in Receptacles		Colors in Jumper		
B+	Red	B+	Red	B+
4	Green & Red	3	Green & White	3
1	Black & White	1	Green	2
6	White	5	White	5
B-	Yellow	B-	Yellow	B-
5	Black	6	Black	6
2	Green	2	Black & White	1
3	Green & White	4	Green & Red	4
0	Red & White	0	Red & White	0

CAR-WIRING DIAGRAM A.C. FOR TYPE 255-F SWITCH GROUP FOR TWO MOTORS

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Nos. *1* and *2*–reverser *1–R1–R1*–forward operating coil–*90–90–90–90–90–90–90–AA1–92–92–AA1–B*—. The reverser is thrown to forward position, and reverser fingers *1* and *R* are connected by the lower reverser segment. Current now flows through *1–R–R–R*–switch group *R–R–R–R*–magnet coils *9*, *10*, *11*, and *12* in parallel. This operates main switches *9*, *10*, *11*, and *12*, and opens their interlocks *A1*, *AA1*, *A1*, and *AA1*.

At the same time, drum finger *B*+ is connected to finger *3A*. Current flows through finger *3A*–contact *3A*–plug–contact *3*–wire *3*, through junction boxes Nos. *1* and *2*–switch group *3–3–3*–interlock *K–3*–magnet coil *1*–common battery wire *B*—. Main switch *1* and its interlock *V* are closed. Autotransformer tap *1* is connected to end *1* of the right-hand preventive coil.

Since the interlocks under switches *11*, *9*, and *1* are closed, current can flow from wire *R*, under the interlock of switch *11*, to interlock *A1–13–13–13–14–14–14–14–14–14*–interlock *V–15–15–15*–magnet coil *2–B*—. Main switch *2* is now closed, connecting autotransformer tap *2* to end *2* of the left-hand preventive coil.

As the interlock under main switch *2* is now closed, current can flow from junction *14* under this interlock to interlock *U–17–17–17–17–17*–magnet coil *3–B*—. Main switch *3* is closed, connecting tap *3* to end *3* of the right-hand preventive coil.

As interlock *U* under main switch *3* is now closed, current can flow from junction *14*, under this interlock, to *19–19–19–19–19*–magnet coil *4–B*—. Main switch *4* is closed, connecting tap *4* to end *4* of the left-hand preventive coil.

Main switches *1*, *2*, *3*, *4*, *9*, *10*, *11*, and *12* and their interlocks are closed on the first notch, as indicated in the table of sequence of switches.

32. Second Notch.—On the second notch, finger *3A*, Fig. 17, drops contact, and finger *4* makes contact with the drum. Opening the circuit of finger *3A* opens main switch *1*, its tap circuit, and its interlock *V*. From drum finger *4*, current flows through wire *4–A1–16–16–16*–interlock *U–15*

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–magnet coil *2*. Switch *2* is held closed, although its control path through interlock *V* is broken. From junction *14*, under interlock *V*, current can now flow to interlock *V* (open)–*21–21–21–21*–interlock *U* (closed)–*22–22–22–22–22*–magnet coil *5–B*–. Main switch *5* and its interlock are closed, and tap *5* is connected to end *5* of the right-hand preventive coil. The manner of advancing the tap connections is similar to that indicated in Fig. 5. Switches *2*, *3*, *4*, *5*, *9*, *10*, *11*, and *12*, Fig. 17, are active on the second notch.

33. Third Notch.—Drum finger *4*, Fig. 17, drops contact, and finger *5* makes contact. Wire circuit *4* is broken; thus, magnet 2 opens main switch *2* and its interlock *U*. Current from drum finger *5* now flows through interlock *A1* of switch *7–18–18*–interlock *U* of switch *3* (closed)–*17–17* –magnet coil *3–B*–. Switch *3* is held closed, although its control path through interlock *U* of switch *2* is open. Current from junction *14*, under interlock *U* of switch *2*, can flow to interlock *U–23–23–23–23*–interlock *K* (closed)–*24–24–24* –magnet coil *6–B*–. Main switch *6* and its interlock are closed. Tap *6* is connected to end *6* of the left-hand preventive coil. Switches *3*, *4*, *5*, *6*, *9*, *10*, *11*, and *12* are active on the third notch.

34. Fourth Notch.—Drum finger *5*, Fig. 17, drops contact, and finger *6* makes contact. Wire circuit *5* is broken; thus, magnet *3* opens main switch *3* and its interlock *U*. From drum finger *6*, current now flows through interlock *AA1* of switch *8–20–20*–interlock *U* (closed)–*19–19* –magnet coil *4–B*–. Switch *4* is held closed, although its control path through interlock *U* of switch *3* is open. Current from junction *14* can now flow through interlock *U* of switch *3–25–25–25–25*–interlock *A1* of switch *6* (closed)– *26–26–26*–magnet coil *7–B*–. Main switch *7* and its interlock are closed. Tap *7* is connected to end *7* of the right-hand preventive coil. Switches *4*, *5*, *6*, *7*, *9*, *10*, *11*, and *12* are active on the fourth notch.

35. Fifth Notch.—Drum finger *6*, Fig. 17, drops contact, and finger *7* makes contact. Wire circuit *6* is broken;

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thus, magnet *4* opens main switch *4* and its interlock *U*. Current cannot flow from drum finger 7, because controller terminal *7* is not connected to any car wire. Interlock *U* of switch *4* is open, so that current can now flow from junction *14* under interlock *V* of switch *1–21–21–21–21*–interlock *U–27–27–27–27*–interlock *A1* of switch 7 (closed)–*28–28–28–28*–magnet coil *8–B—*. Main switch *8* and its interlock are closed. Tap *8* is connected to end *8* of the left-end preventive coil. Switches *5*, *6*, *7*, *8*, *9*, *10*, *11*, and *12* are active on the fifth notch.

36. Five distinct voltages are impressed on the motor circuit by the action of the controller; thus, five efficient running notches are provided. From point *C*, Fig. 17, on the wire leading from the center of the upper preventive coil, current flows through the windings of the two motors, which are connected in parallel. With some motors, shunts across the field coils are used, but with other motors, they are omitted.

37. Fifth Reverse Notch.—To reverse the direction of movement of the car, the controller handle is thrown to the left. On the first reverse notch, Fig. 17, drum fingers *B+* and *2* are active. Current flows from drum finger *2* through junction boxes Nos. *1* and *2*–reverser *2–2–2–R2* now connected to *2*, as the reverser control segments are now assumed to be at forward position–*R2* operating coil–*90–90*–switch group *90–90–90*–interlock *AA1* of switch *12–92–92*–interlock *AA1* of switch *10–B— –B—*. The reverser operating coil *R2* forces the reverser contact segments to reverse position. Reverser finger *R2* drops contact with its segment, thus breaking connection between it and finger *2*. At the same time finger *R* makes contact with the same segment. Current flows from reverser finger *2* to finger *R–R*–wire *R*–switch group *R–R–R–R—* –magnet coils *9*, *10*, *11*, and *12*, in parallel, thus operating the main switches *9*, *10*, *11*, and *12*.

The action of the other control magnets and main switches is the same on the reverse notches as it is on the forward notches. The main field-coil connections of the motors are reversed; therefore, the rotation of the motors is reversed.

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Assuming the reverser to be in its reverse position, as indicated by the position of the reverser control segments in Fig. 17, and the controller to be on the first forward notch, current from drum finger *1* flows to reverser finger *1*–finger *R1*–operating coil *R1–90*–through interlocks of open switches *12* and *10–B*—. Operating coil *R1* forces the reverser segments into their forward position, and the motors are then connected for forward rotation.

LATER TYPE ALTERNATING-CURRENT, UNIT-SWITCH CONTROL, CAR-WIRING DIAGRAM, SCHEDULE M

38. In Fig. 18 is shown a later type of alternating-current, unit-switch control system. This control system is similar in general to that shown in Fig. 17, but differs slightly in respect to the control wiring on some of the interlocks, the control wiring for the operation of the pantagraph trolley, and the jumper and receptacle wiring; also, in that the shunts to the motor field coils are removed. The operation of this system differs but slightly, however, from that explained in connection with Fig. 17.

WESTINGHOUSE UNIT-SWITCH, ALTERNATING-CURRENT AND DIRECT-CURRENT CONTROL, SCHEDULE T

39. The connections of the motors and main switches for the unit-switch, alternating- and direct-current control system, schedule T, for four motors of a capacity above 75 horsepower and including 100 horsepower, each, are shown in Fig. 19. When alternating-current control is used, switches Nos. *9*, *10*, and *12* are closed, thus connecting the pairs of motors in parallel. The action of the other alternating-current switches is similar to that described in connection with Fig. 17. On the first direct-current step, Fig. 19, switches Nos. *9*, *11*, and *301J* are closed. The four motors are then connected in series, with all the resistance in circuit. A resistance section is cut out on each of the succeeding steps, so that on the fifth step, only the four motors are in series across the line.

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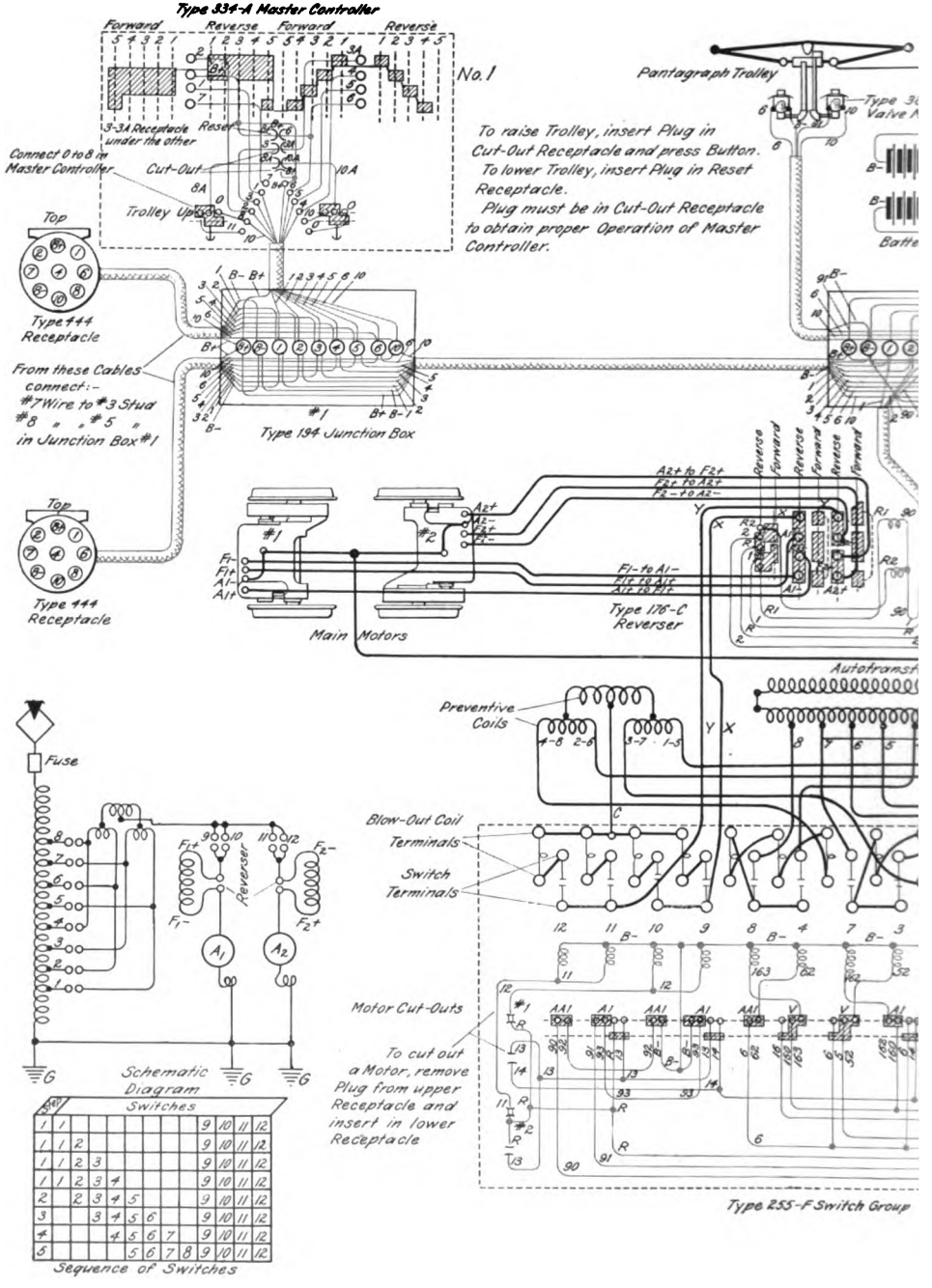
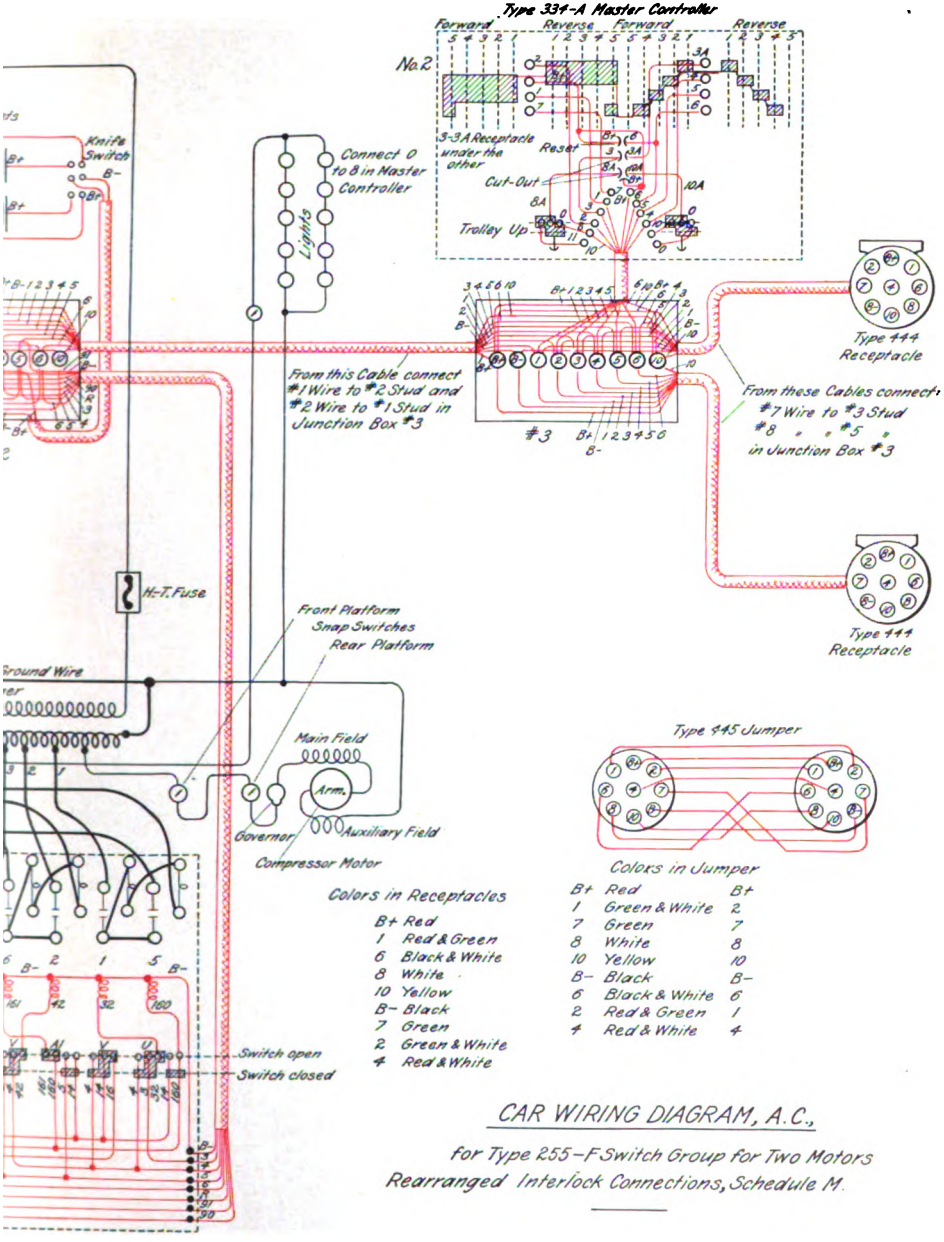

Type 834-A Master Controller
Forward
Reverse
Forward
Reverse
No. 1
Pantagraph Trolley
To raise Trolley, insert Plug in Cut-Out Receptacle and press Button. To lower Trolley, insert Plug in Reset Receptacle.
Plug must be in Cut-Out Receptacle to obtain proper Operation of Master Controller.
3-3A Receptacle under the other
Reset
Cut-Out
Connect 0 to 8 in Master Controller
Trolley Up
Top
Type 444 Receptacle
From these Cables connect:-
#7 Wire to #3 Stud
#8 " " #5 "
in Junction Box #1
Type 194 Junction Box
Top
Type 444 Receptacle
Main Motors
Type 176-C Reverser
Autotransf
Preventive Coils
Fuse
Blow-Out Coil Terminals
Switch Terminals
Motor Cut-Outs
To cut out a Motor, remove Plug from upper Receptacle and insert in lower Receptacle
Schematic Diagram
Switches
Sequence of Switches
Type 255-F Switch Group

FIG



CAR WIRING DIAGRAM, A.C.,

for Type 255-F Switch Group for Two Motors
Rearranged Interlock Connections, Schedule M.

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A change-over switch is provided. This switch is operated by two relays, so that when alternating current is used, the alternating-current relay operates to move the switch into its alternating-current position. When direct-current is used, the direct-current relay operates to move the switch into its direct-current position. All the circuits from the master

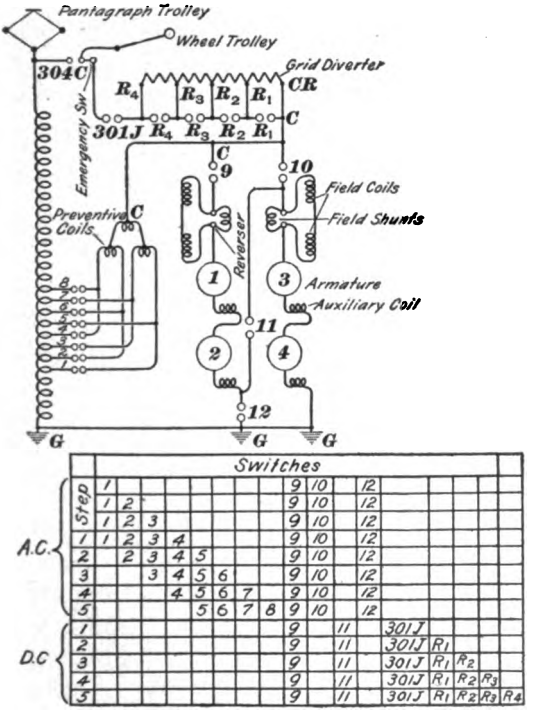

FIG. 19

controllers to the various switches pass through the change-over switch. In exactly the same way, the movement of the master controller operates the proper switches for direct- or alternating-current operation, according to which current is in use and the position of the change-over switch.

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WESTINGHOUSE UNIT-SWITCH, ALTERNATING-CURRENT AND DIRECT-CURRENT CONTROL, SCHEDULE T-1

40. In Fig. 20 is shown a car-wiring diagram for alternating- and direct-current unit-switch control, types 255-H and 251-J switch groups, schedule T-1, with four motors. The change-over switch is operated for direct current as follows: The plug is inserted into the controller cut-out of the left-hand controller. Contact *B*+ is connected to contact *8A*, and current flows to *8A*–stud *11*–wire *8*–contact point *8* on *A*.-*C*. relay (lower position)–*81* on *D*.-*C*. relay (upper position, as relay is now active)–*81*–*D*.-*C*. operating coil of change-over switch–*83*–change-over switch segment, if switch has been left at *A*.-*C*. position–*B*−. The switch is pulled to the direct-current position. If alternating current is to be used, wire *8* connects to upper point *8* on the alternating-current relay (now active) and current flows across the disk contact to *82* (lower position of *D*.-*C*. relay)–*82*–*A*.-*C*. operating coil of change-over switch–*84*–*B*−. If the switch is in direct-current position, it is pulled into alternating-current position.

DIRECT-CURRENT OPERATION

41. When the controller is thrown to the **first notch,** finger *3A* is active, and current flows through the plug to contact *3* of the *D*.-*C*. line-switch cut-out–wire *3*–finger *30* on the change-over switch–interlock of *D*.-*C*. line switch–*33*–line-switch operating coil–*34*–*B*−. The line switch is thus closed.

Finger *1* is the forward reverser finger. When this finger is active, the reverser is thrown to forward position. Wire *R* at the reverser is now active, and the operating coil of switch *9* takes current from this wire. Switch *9* closes. Finger *11* on the change-over switch is energized from finger *R*, and current flows through *11*–*110*–*111*–*112*–operating coil of switch *11*. Switch *11* closes. The four motors are in series, with all the resistance sections in circuit.

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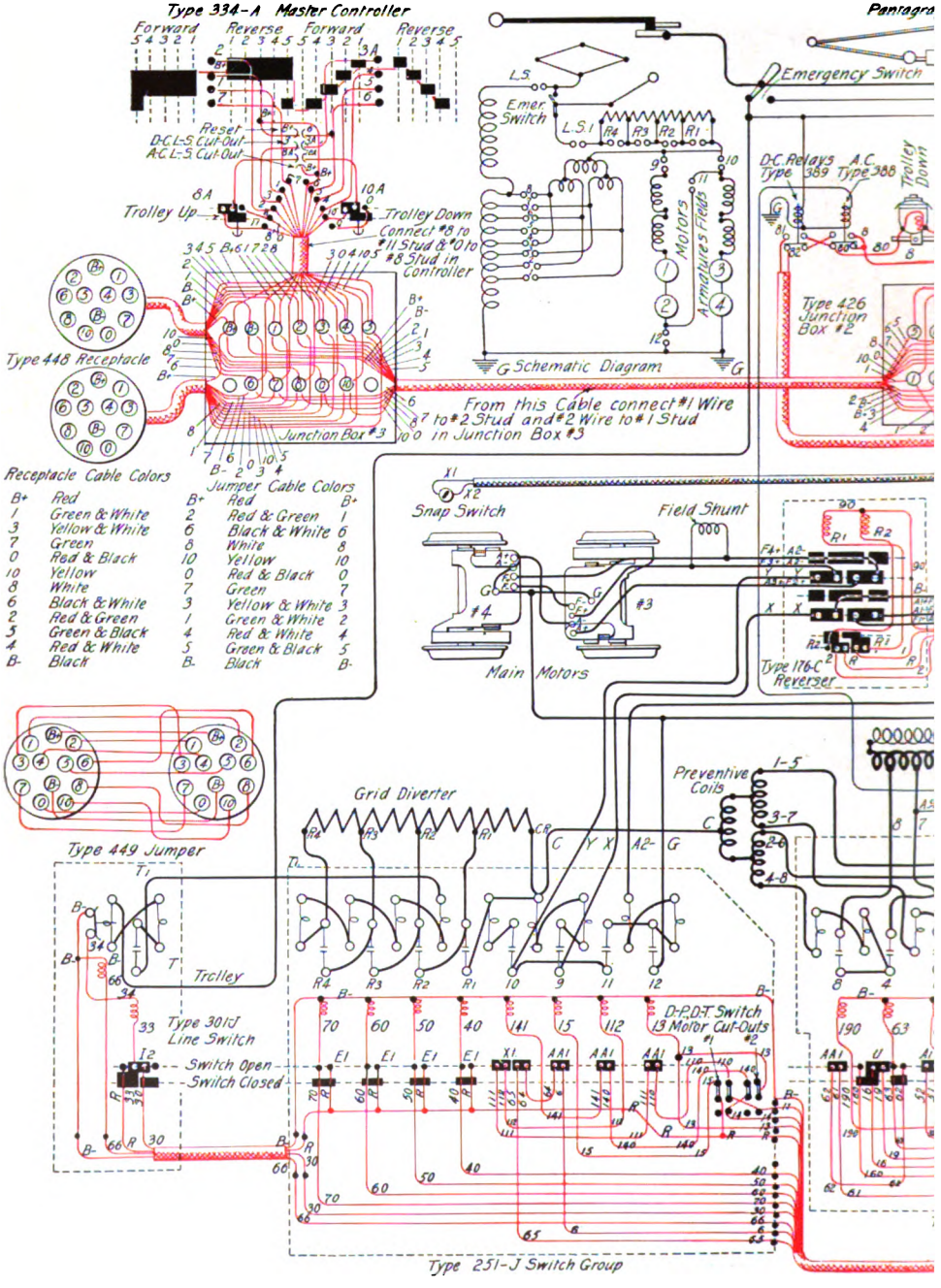

FIG.

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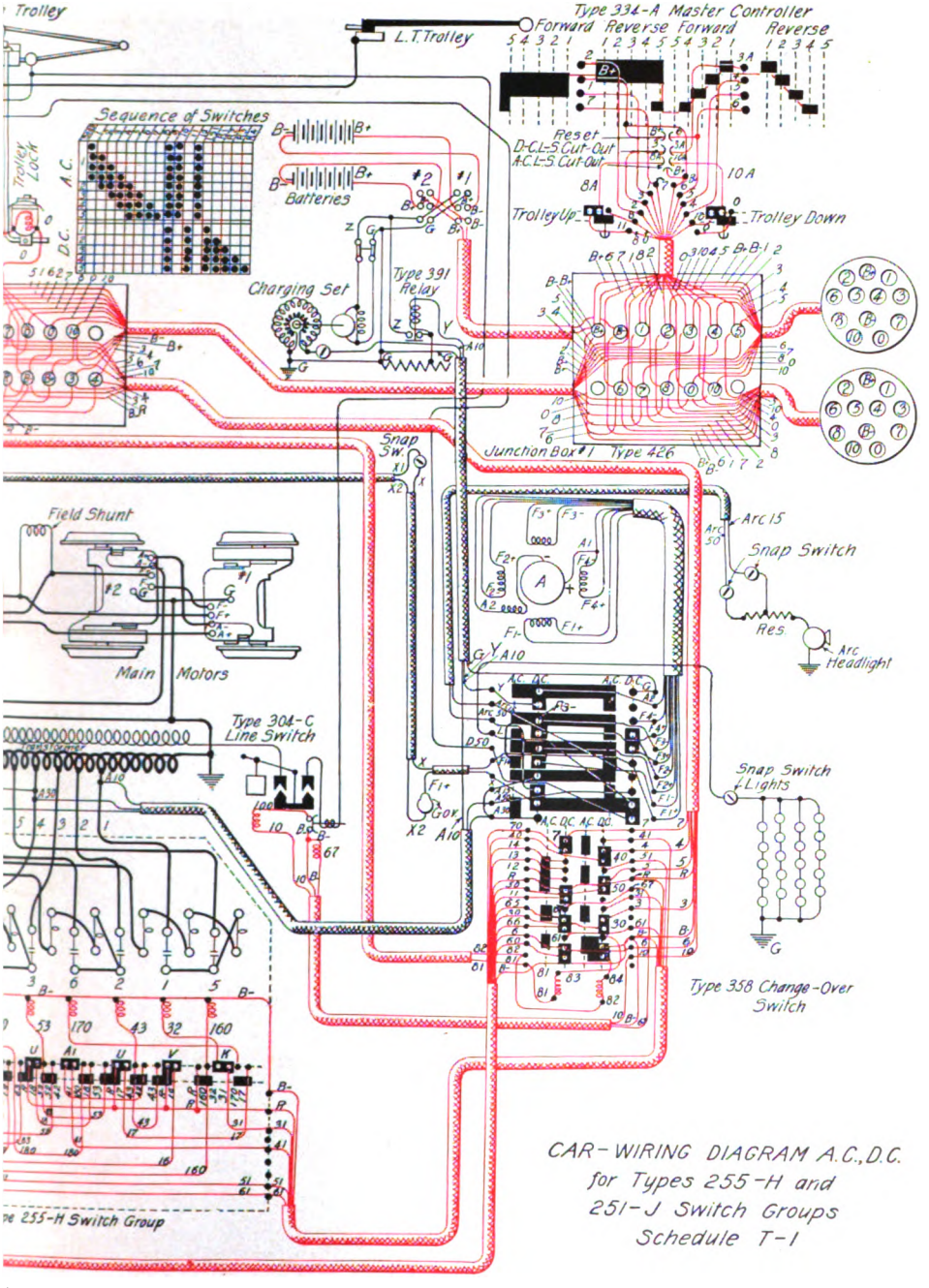

CAR-WIRING DIAGRAM A.C., D.C.
for Types 255-H and
251-J Switch Groups
Schedule T-1

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Further movement of the controller energizes fingers *4*, *5*, *6*, and *7* and cuts out the four resistance sections. The four motors are now in series, with all the resistance sections cut out.

ALTERNATING-CURRENT OPERATION

42. The alternating-current line switch is closed by current that flows from *B*+ through cut-out contact *10A* (plug in *A*.-*C*. line-switch cut-out)–finger *10*–wire *10*–operating coil of the *A*.-*C*. line switch–*B*−. The pantagraph trolley is raised after the plug is inserted in the alternating-current, line-switch cut-out by pressing the left-hand button at the base of the controller. Stud *8* and wire *0* are now active, and current flows through the operating coil of the trolley lock. The latch on the trolley is released, and the trolley is forced upwards by its springs.

As soon as the trolley touches the trolley wire, current flows through the alternating-current relay from autotransformer tap *4*. Contact is broken between lower points *8* and *80*. Therefore, when the left-hand button on the base of the controller is released and finger *8A* is connected to stud *11* and wire *8*, no current can flow between points *8* and *80* and through the trolley-down magnet because of the break in the circuit at the alternating-current relay. If the trolley is to be lowered, the right-hand button is pushed, thus breaking wire circuit *10* and opening the alternating-current, 304-C line switch. The alternating-current relay contact plate drops and completes wire circuit *8* through the trolley-down magnet. Air under pressure is forced into the main cylinder of the pantagraph, and the trolley is lowered and automatically latched. If the trolley is to remain down, the plug may be drawn out of the alternating-current, line-switch cut-out. For alternating-current control, the plug is inserted in the alternating-current, line-switch cut-out, and the change-over switch is then forced to its alternating-current position, as previously explained.

43. On the **first notch**, either finger *1* or *2* is active, depending on whether the controller is thrown to forward

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or to reverse position. Wire *R* is energized (which also energizes wires *14* and *13* at the alternating-current position of the change-over switch) and switches *9*, *10*, and *12* are closed. Switch *1* is closed by current through finger *B*+ – finger *3A*–plug–wife *3–A.-C.* segment of change-over switch –wire *31–32*–operating coil of switch *1*. Switch *2* is closed by current from wire *R* through the closed interlock of switch *1* and wire *43*. Switch *3* is closed by the current passing through the closed interlock of switch *2* and wire *53*. Switch *4* is closed by the current passing through the closed interlock of switch *3* and wire *63*.

44. On the **second notch,** finger *3A* drops contact, and switch *1* opens. When wire *4* becomes active, wire *41* is energized at the change-over switch and switch *2* is held closed. The current can now flow through wire *R*–interlock of switch *1* (open)–*16*–interlock of switch *4* (closed)–*160*–operating coil of switch *5*. Switch *5* closes.

45. On the **third notch,** finger *4* drops contact, and finger *5* is energized. Switch *2* opens, because wire *41* is dead and because circuit *R*, through its operating coil, was broken when switch *1* opened. Current from wire *R* flows through the interlock of switch *2* (open)–*17–17*–interlock of switch *5* (closed)–operating coil of switch *6*. Switch *6* closes. Circuit *R*, through the operating coil of switch *3*, is broken by the interlock of switch *2* (now open), but current flows through operating coil *3* from wires *5* and *51*.

46. On the **fourth notch,** wires *5* and *51* are dead, and wires *6* and *61* are active. Switch *3* opens because wire *51* is dead. Current from wire *R* flows through the interlock of switch *3* (open)–*18–180*–operating coil of switch *7*. Switch *7* closes. Circuit *R*, through the operating coil of switch *4*, is now broken, but the coil obtains current from wires *6* and *61*.

47. On the **fifth notch,** wires *6* and *61* are dead, and switch *4* opens. Wire *7* is dead when the change-over switch is at its alternating-current position. Current from

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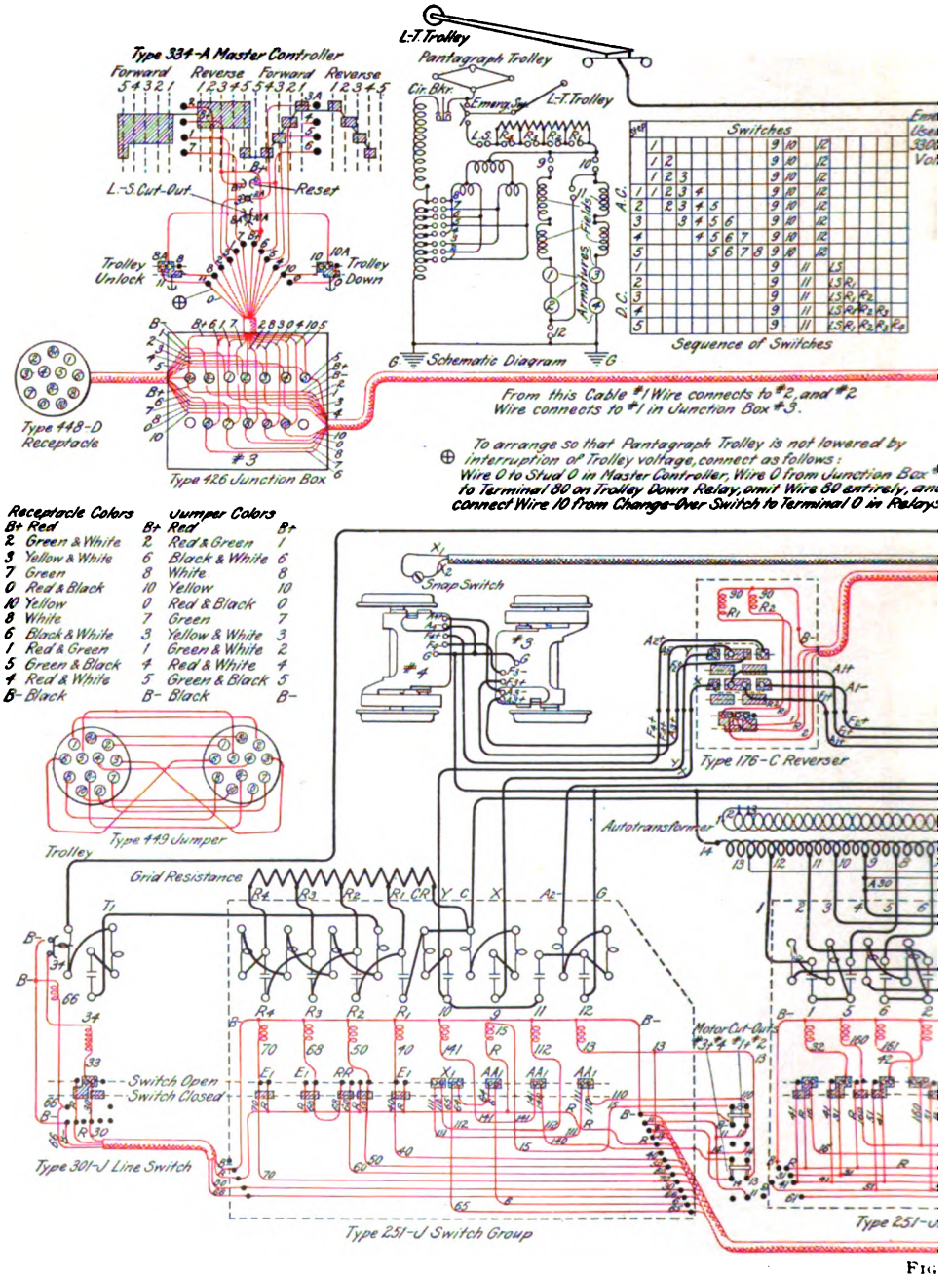

FIG.

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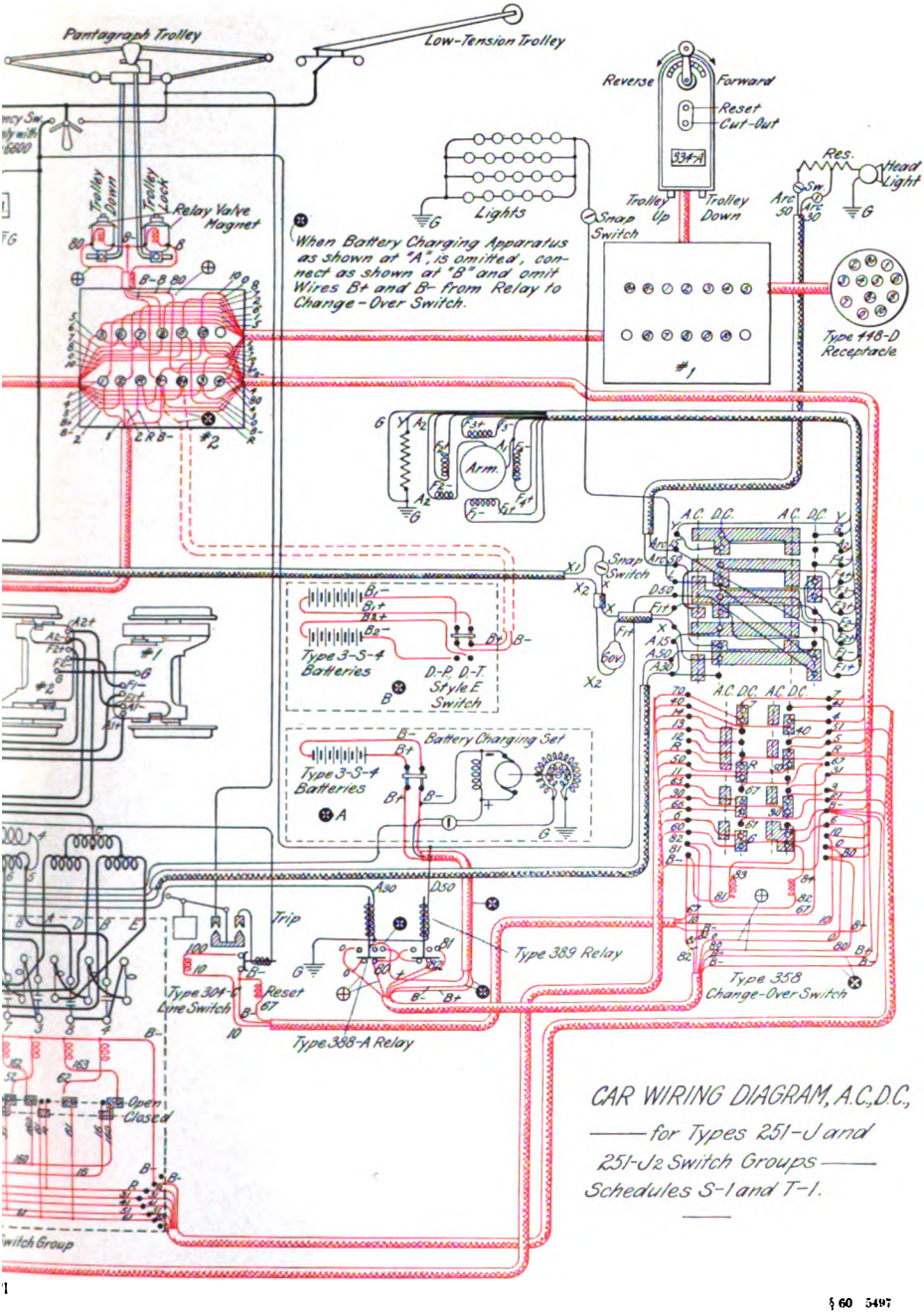

CAR WIRING DIAGRAM, A.C.,D.C.,
—— for Types 251-J and 251-J2 Switch Groups ——
Schedules S-1 and T-1.

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circuit *R* can now flow through the interlock of switch *1–16–19–190*–operating coil of switch *8*. Switch *8* closes. The maximum electromotive force is now impressed on the motors.

WESTINGHOUSE UNIT-SWITCH, ALTERNATING-CURRENT AND DIRECT-CURRENT CONTROL, SCHEDULES S-1 AND T-1

48. In Fig. 21 is shown a car-wiring diagram for alternating- and direct-current unit-switch control, schedules S-1 and T-1, switch groups 251-J and 251-J2. The operation of this system is in general quite similar to that explained in connection with Fig. 20. The 255-H switch group shown in Fig. 20 is replaced by the 251-J2 switch group, Fig. 21. The direct- and alternating-current relays are shown near the change-over switch in Fig. 21. The resistance shown just to the left of the pump motor is used in series with the pump motor when the direct-current voltage is above 500 volts.

GENERAL ELECTRIC T-47 CONTROLLER CAR-WIRING DIAGRAM

49. In Fig. 22 is shown a car-wiring diagram for two T-47 hand controllers and four motors arranged for operation on alternating-current circuits. When the car is to be operated, the oil switch is closed by hand, thus exciting the compensator. The retaining coil of the oil switch is excited by current from compensator tap *T3* passing through two hood switches. If the line should become dead, or if either one or both of the hood switches should be opened, the retaining coil would become deenergized and the oil switch would open the circuit between the trolley and the compensator.

50. First Point.—The reverse switch on controller No. *1* is assumed to be at the forward position and the power drum at the first point. For the purpose of tracing the current paths, it is assumed that the trolley is positive. Tap *T2* is

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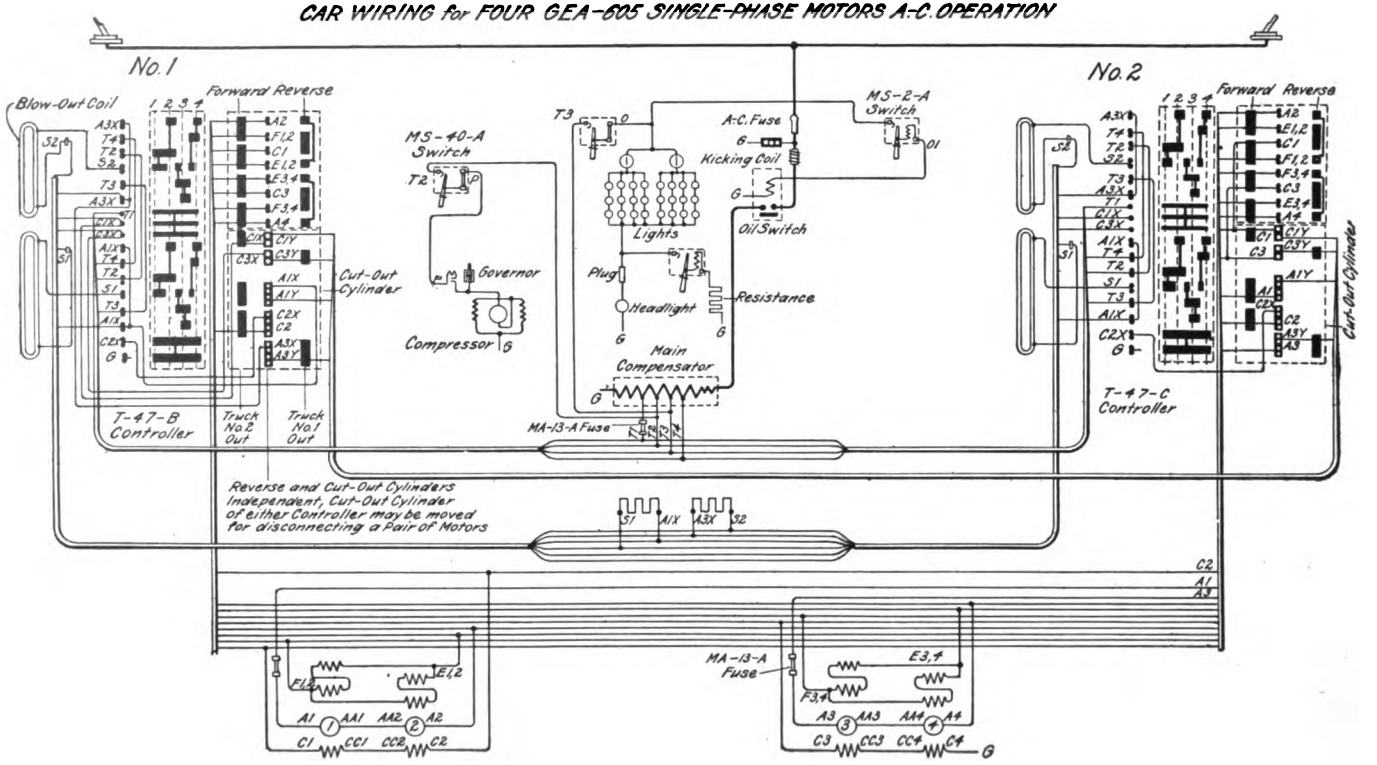

FIG. 22

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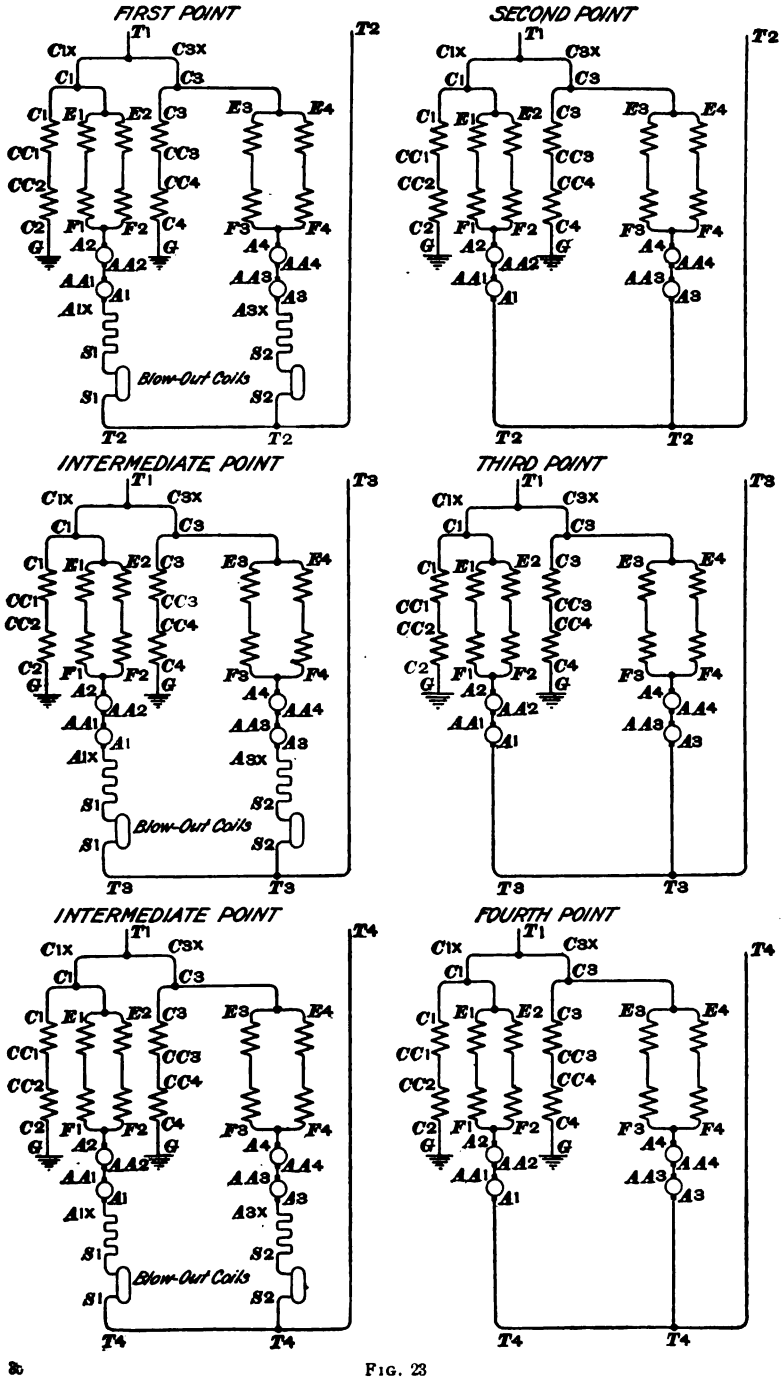

FIG. 23

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positive to tap *T1* and tap *T1* is positive to the ground. Current flows from tap *T2*–finger *T2*–finger *S1*–blow-out coil–*S1*–*S1*–resistance coil–*A1X*–*A1X*–*A1X* on cut-out–*A1Y*–*A1Y*–*A1*–*A1*–*A1*–armature No. *1*–*AA1*–*AA2*–armature No. *2*–*A2*–*A2*–*F1*,*2*–*F1*,*2*–main-field coils of motors Nos. *1* and *2* in parallel–*E1*,*2*–*E1*,*2*–*C1* on the reverse switch of controller No. *1*–*C1* on cut-out No. *2*–*C1Y*–*C1Y*–*C1X*–finger *C1X*–finger *T1*–transformer tap *T1*. Current also flows from finger *C1* on reverse switch No. *1*–*C1*–compensating coil–*CC1*–*CC2*–compensating coil–*C2*–*C2*–*C2X*–finger *C2X*–*G*. Current from tap *T2* also flows through upper finger *T2* on controller No. *1* and motors Nos. *3* and *4* in a similar manner, as indicated in Fig. 23.

With this method of connection, the compensating coils of all the controller points are connected between compensator tap *T1* and the ground, and the main motor windings of the pairs of motors are connected in parallel between *T2*, or *T3*, or *T4* and *T1*, depending on the position of the controller drum. The motor connections are shown diagrammatically in Fig. 23.

51. Second Point.—On the second point, upper fingers *A3X* and *A1X*, Fig. 22, are active and the resistance section and blow-out coil for each pair of motors are cut out of circuit, thus leaving the main motor windings of the pairs of motors connected directly between compensator taps *T2* and *T1*, as shown in Fig. 23.

52. Third Point.—On the third point, Fig. 22, transformer tap *T3* and fingers *T3* are active. Fingers *T2* are now inactive. In passing from the second point to the third point, the resistance sections and blow-out coils are first connected between the motors and tap *T3*, but when the full third position is reached, the resistance sections and blow-out coils are cut out of circuit, as indicated in Fig. 23.

53. Fourth Point.—On the fourth point, transformer tap *T4* and fingers *T4*, Fig. 22, are active. Fingers *T3* are now inactive. The resistance sections and blow-out coils are cut into the circuit on the intermediate position, and cut

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out of circuit on the full fourth position. The main motor windings of the pairs of motors are now connected between

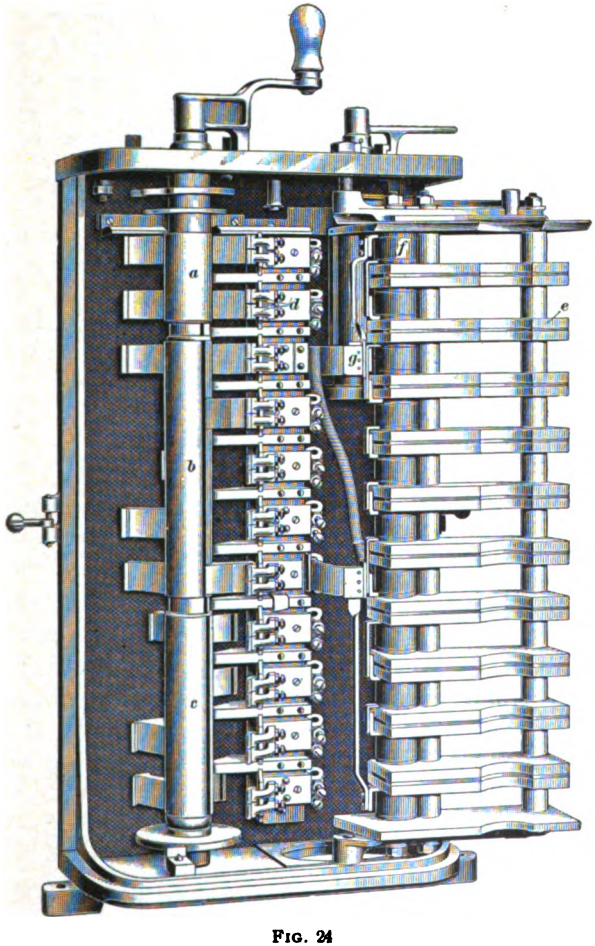

FIG. 24

taps *T4* and *T1* and have maximum electromotive force impressed on their terminals. The connections are indicated in Fig. 23.

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GENERAL ELECTRIC T-33 CONTROLLER

54. In Fig. 24 is shown a **T-33, hand-operated controller** that is arranged for the control of motors on either alternating- or direct-current circuits. The controller drum is divided into three sections *a*, *b*, and *c* that are insulated from each other. The fingers *d* bear on the drum segments when the controller is in operation. The arc guards *e*, when in their closed position, pass between the contact segments and thus prevent current from arcing across from segment to segment. Small blow-out magnets *f* that are provided with polar extensions embedded in the arc guards, serve to disrupt any arc that may tend to hold between the segments and the fingers. The reverse switch is shown at *g*.

T-33-A CONTROLLER CAR-WIRING DIAGRAM

55. In Fig. 25 is shown a car-wiring diagram arranged for T-33-A controllers and four motors, operating on either alternating- or direct-current circuits. The alternating- and direct-current main switches are provided with retaining coils. After a main switch has been closed, the retaining coil holds it in that position until the voltage drops to half of its normal value, when the coil automatically releases and opens the switch. A retaining-coil switch *RS* is placed in each cab, and the main switch may be thrown open by operating either retaining-coil switch.

DIRECT-CURRENT CONTROL

56. The action of controller No. *1*, Fig. 25, will be considered. The reverse-switch fingers are assumed to be in contact with the left-hand, or forward, segments, and the commutating switch is thrown by hand so that the fingers rest on the direct-current segments. The direct-current main switch is closed by hand, and both retaining switches are thrown over so that the right-hand blades connect *2A*

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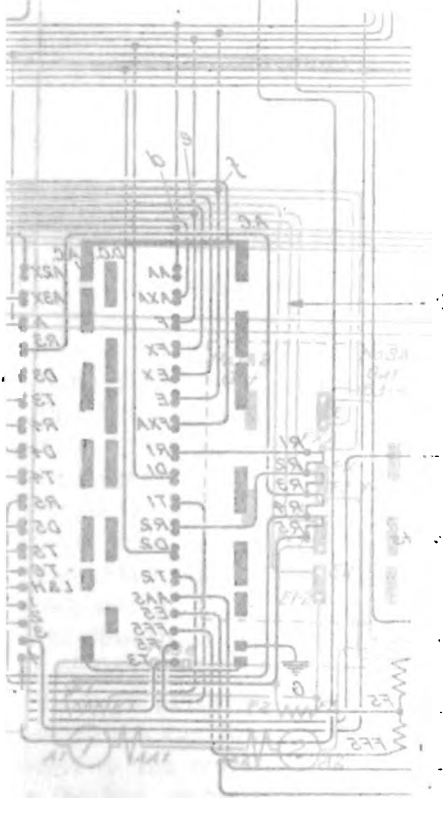

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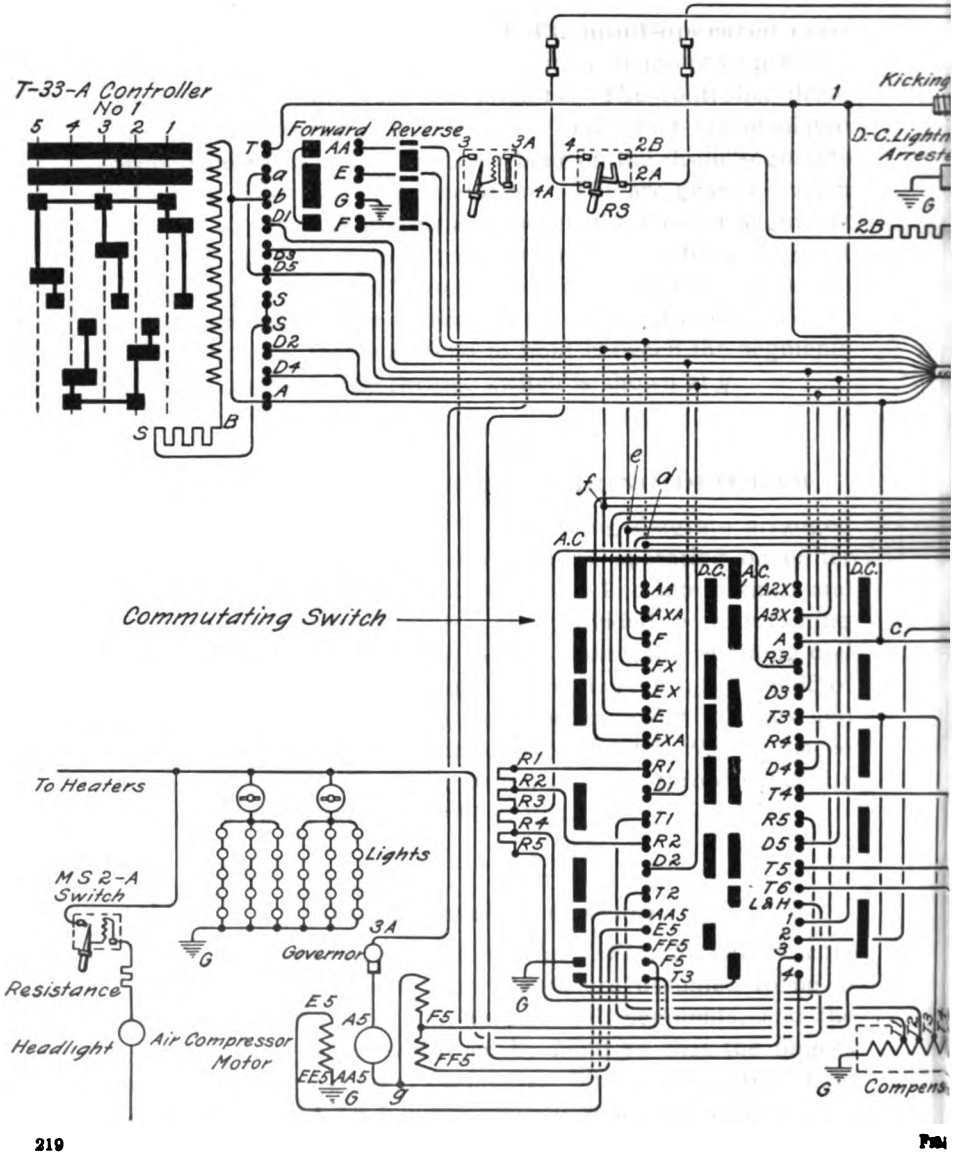

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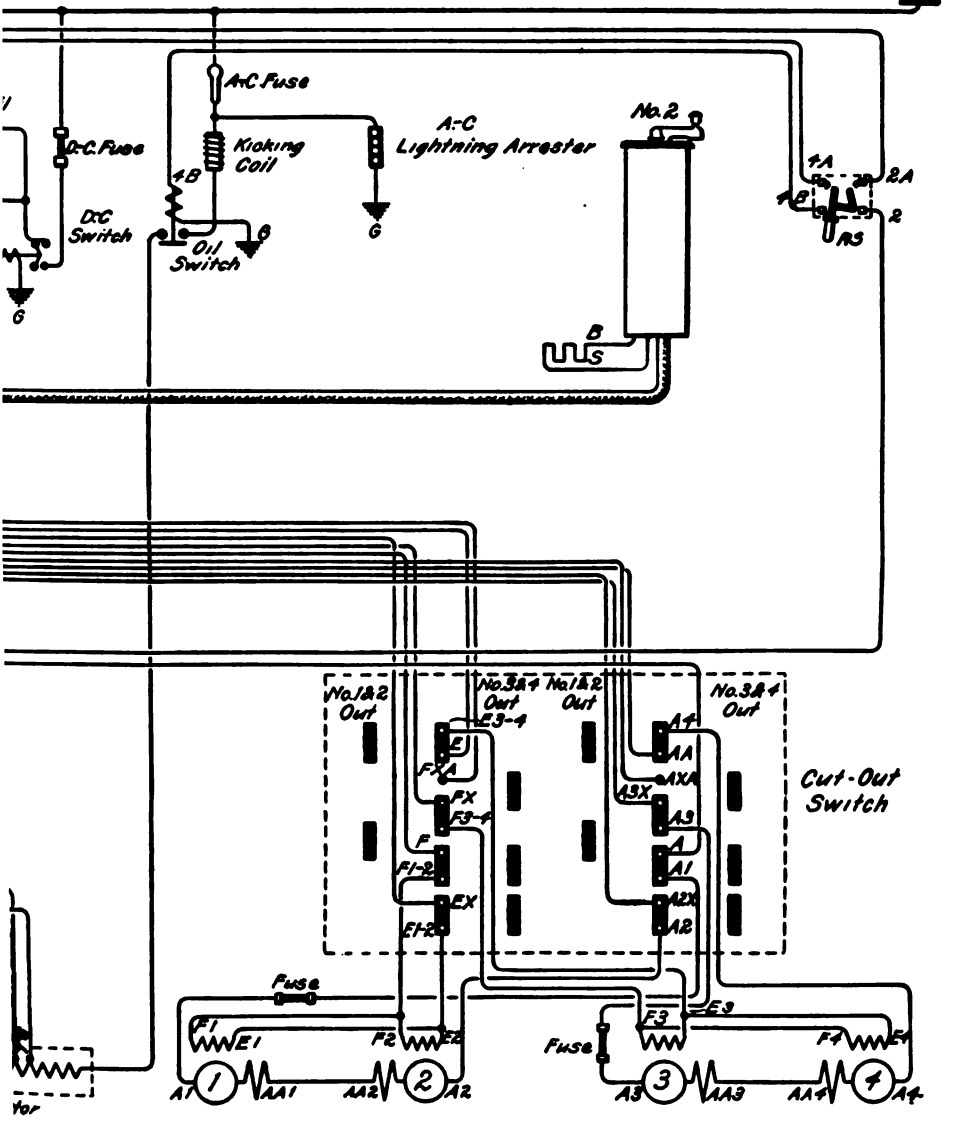

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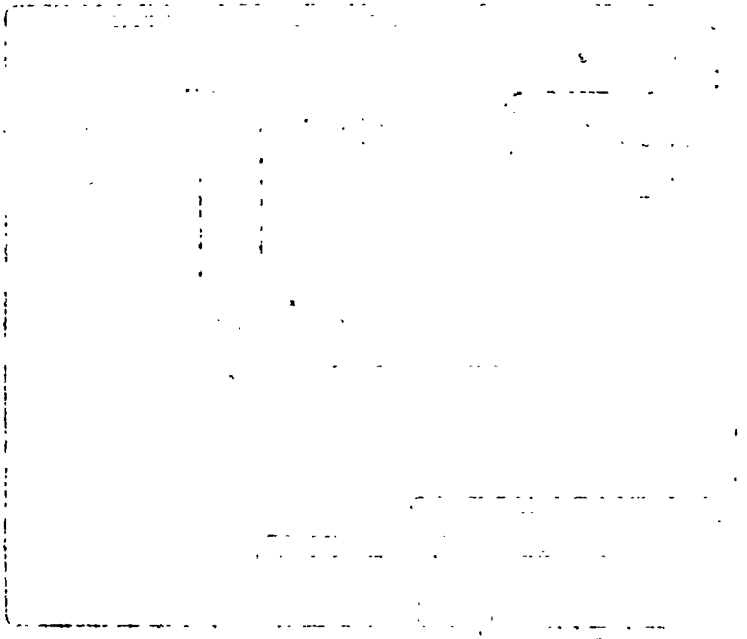

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with *2B*, and *2* with *2A*. The current through the retaining coil takes the following path: Trolley–*D.-C.* fuse–*D.-C.* switch–kicking coil–*1*–finger *1* on commutating switch–*D.-C.* segment–*2–2–2A–2A–2B–2B*–resistance–retaining coil–ground at *G*.

57. When the controller, Fig. 25, is advanced to the **first point,** current flows through the kicking coil to finger *T* on the controller. From this point, the path is: *T*–drum segments–*a–D5–D5–R5–R5–R4–R3–R2–R1–R1–D1–D1–b–A–A* on cut-out switch–*A1*–fuse–*A1–1–AA1–AA2–2–A2–A2–A2X–A2X–A3X–A3X–A3*–fuse–*A3–3–AA3–AA4–4–A4–A4–AA–d–AA* reverse switch–forward segments–*F–e–F* on the cut-out switch–*F1-2*–Nos. *1* and *2* fields in parallel–*E1-2–EX–EX–FX–FX–F3-4*–fields Nos. *3* and *4* in parallel–*E3-4–E–f–E* reverse switch–*G*. The four motors and all the resistance sections are in series. The four armatures and their compensating coils are in series. The four fields are divided into two sets, which are in series, each set consisting of two fields in parallel.

58. On the **second point,** finger *D2*, Fig. 25, is connected to finger *A*. Drum finger *D2* is also connected to commutating-switch finger *D2*, which is connected by the *D.-C.* segment to resistance tap *R2*. One section of resistance, that between *R1* and *R2*, is thus cut out, because current can now flow directly from controller-drum finger *D2* to the drum segment, to finger *A*, and then to the motors. From finger *T*, the path is: *T–a–D5–D5–R5–R5–R4–R3–R2–R2–D2*–drum finger *D2–A*–motors.

On the **third point,** fingers *D3* and *b* cut out one more resistance section.

On the **fourth point,** fingers *D4* and *A* cut out another section of resistance.

On the **fifth point,** the last resistance section is cut out, because current can flow from *T–a–D5*–left-hand drum segment–*b–A*–to the motors. The motors are now in series across the line, without the starting resistance.

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ALTERNATING-CURRENT CONTROL

59. The alternating-current main switch, Fig. 25, is closed by hand, thus exciting the compensator; current flows from the trolley through the alternating-current fuse, the alternating-current kicking coil, the alternating-current oil switch, and the compensator, to the ground. Both switches *RS* are thrown so that the left-hand blades connect *4* with *4A*, and *4A* with *4B*. The commutating switch is moved by hand so that the fingers make contact with the alternating-current segments. The current for the retaining coil of the main alternating-current oil switch is taken from the compensator tap *T3*. The path is: Tap *T3*–*T3* of left-hand set of commutating-switch fingers–*A*.-*C*. segments–*4*–*4*–*4A*–*4A*–*4B*–*4B*–retaining coil–ground at *G*.

60. On the **first point**, when the drum fingers first touch the drum segments, the path of the current from the low-voltage compensator tap *T1* is as follows: *T1*–*T1*–*A*.-*C*. segment–*D1*–*D1*–*S*–*S*–resistance section *SB*–separate blow-out coils–*A*–junction *C*. From this point the current divides, part of it passing through armatures Nos. *1* and *2* in series, and the rest of the current through armatures Nos. *3* and *4* in series. The currents join again at junction *d* and follow the path: reverse-switch finger *AA*–*F*–junction *e*–through the four fields in parallel–junction *f*–reverse-switch finger *E*–*G*. The armatures are divided into two sets, which are in parallel, each set consisting of two armatures and their respective compensating coils in series. All the fields are in parallel.

When the controller-drum movement to its first point is completed, the resistance section and the blow-out coils are cut out, and current flows from finger *D1* to *b*, to *A*, and thence to the motors. The resistance section *SB* is used in order to prevent short-circuiting a section of the compensator as the drum is turned from point to point. The separate blow-out coils and the resistance are thrown across the terminals of a section of the compensating coil during the transition period from point to point, and are cut out

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when the drum reaches its full position for any point. When the drum passes from the first point to the off-position on either direct- or alternating-current operation, the resistance *SB* and the blow-out coils are thrown in circuit; this reduces the current and at the same time blows out the arcs that may have formed at the ends of the drum segments.

61. On the **second point,** finger *D2*, Fig. 25, makes contact with its drum segment. Resistance *SB* and the blow-out coils are cut in and then cut out of circuit, and, on the full point, current flows from tap *T2* on the compensator to *T2–D2–D2–A*, and thence to the motors.

On the **third point,** finger *D3*, which is connected to compensator tap *T3*, is thrown into action.

On the **fourth point,** finger *D4* and tap *T4* are active.

On the **fifth point,** finger *D5* and high-voltage motor tap *T5* are active, and the motors receive their maximum electromotive force.

OPERATION OF AUXILIARY APPARATUS

62. Each pair of motors, Fig. 25, is provided with a cut-out switch, by means of which either pair of motors may be cut out. On direct-current operation, the car lights, headlights, and heaters receive current through fingers *1* and *L & H* on the commutating switch. On alternating-current operation, they receive current through compensator tap *T6–T6–L & H.*

The air-compressor motor on direct-current operation receives current through finger *1* on the commutating switch–*3–3–3A–3A*–governor–*A5–AA5*–junction *g–F5–FF5–FF5–E5–E5–EE5–G.* The armature and all the field coils are in series.

The compressor motor on alternating-current operation receives current through tap *T3–T3* of the left-hand set of fingers on commutating switch–switch segments–*3–3–3A–3A*–governor–*A5–AA5*–junction *g*; here the current divides, one path leading through *F5* to ground, and the other through finger *AA5–E5–E5–EE5* to ground at *G.* The sections of field coils *g–F5* and *E5–EE5* are in parallel.

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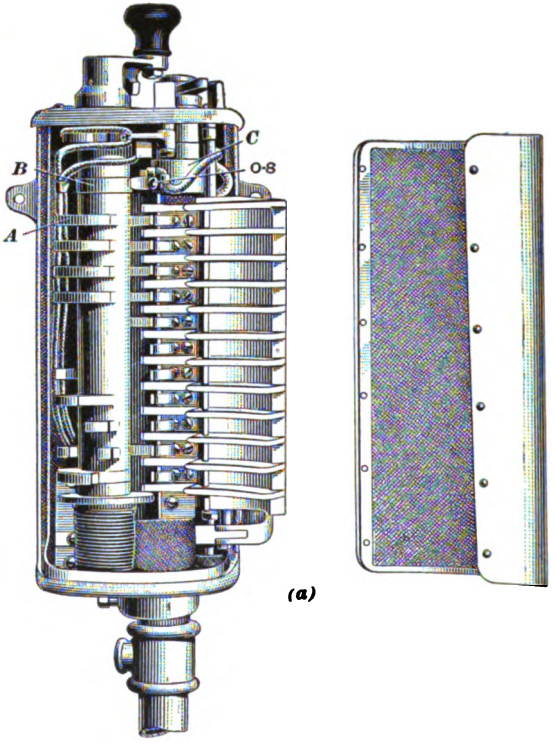

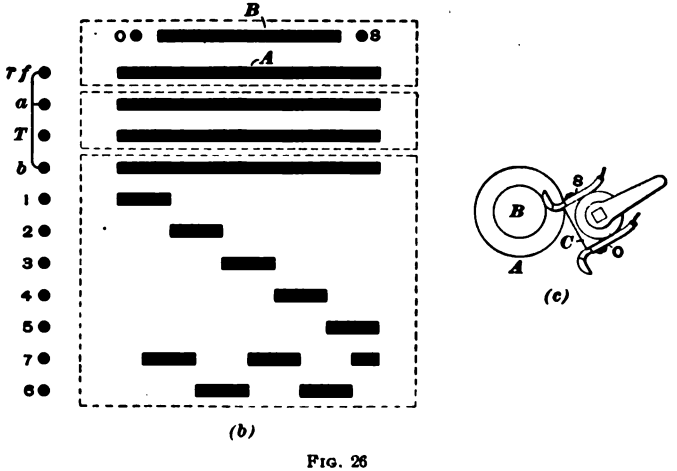

FIG. 26

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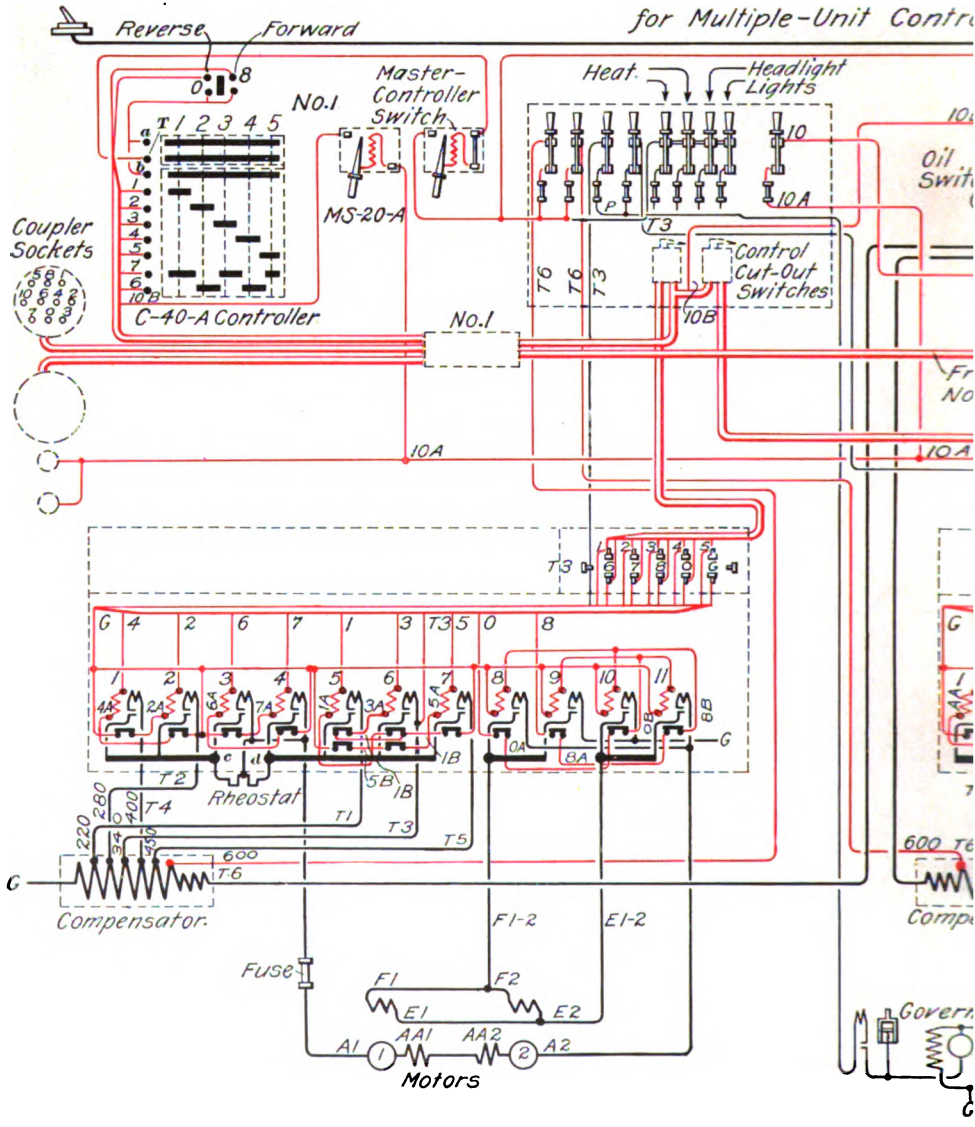

FIG

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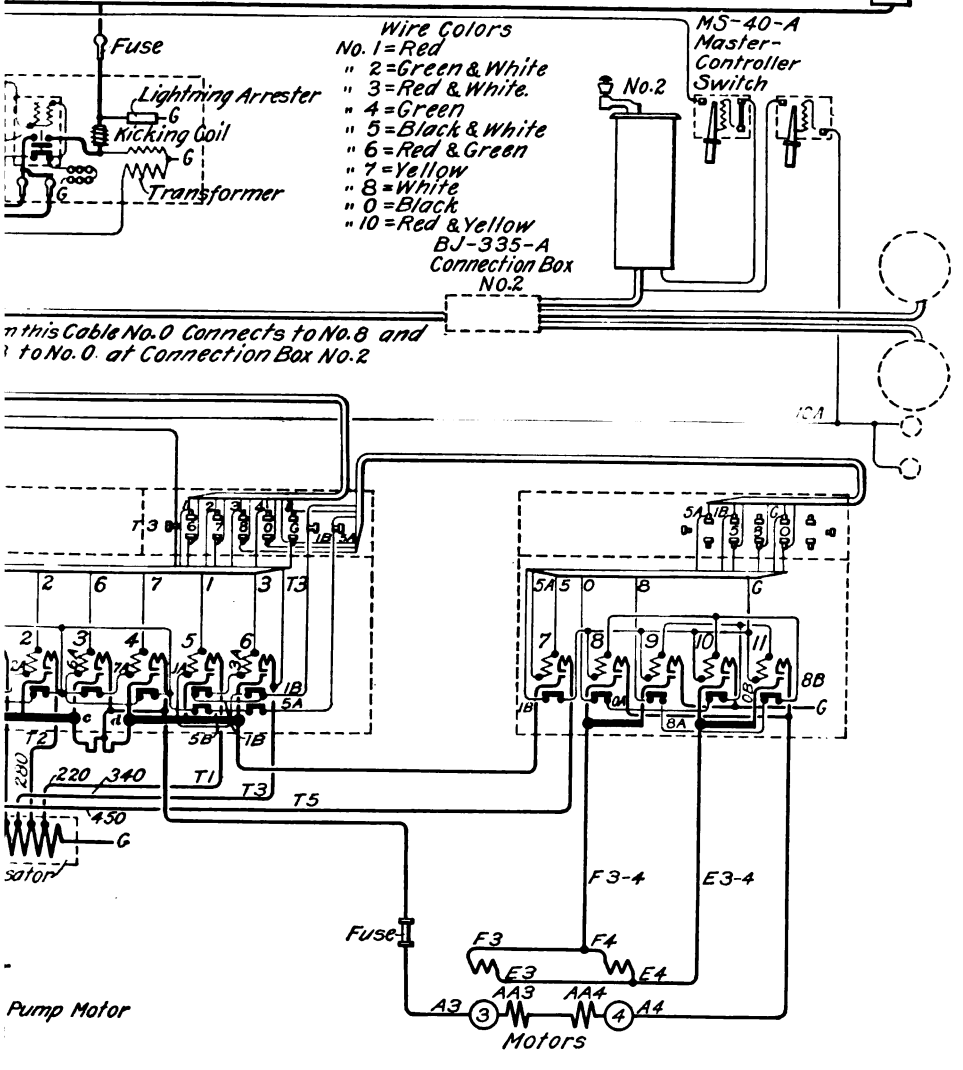
IG DIAGRAM

' Type M A:C. Operation



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SPRAGUE-GENERAL ELECTRIC MULTIPLE-UNIT SYSTEM

C-40-A CONTROLLER FOR ALTERNATING-CURRENT CONTROL

63. The type C-40-A controller is shown in Fig. 26 (*a*). The segments opposite the eight lower fingers [*b* to *6*, Fig. 26 (*b*)] constitute the accelerating section of the drum; the power section takes in the two segments opposite the fingers *T* and *a*; and the reverse section consists of segment *A* opposite finger *rf*, and segment *B* opposite either finger *0* or *8*. Segments *A* and *B* are electrically connected and receive current through finger *rf*. The reverse fingers *0* and *8* (one directly behind the other) are mechanically connected to the reverse cylinder *C*, Fig. 26 (*a*). Either one of the fingers *0* or *8* may be connected to drum segment *B* by throwing the reverse handle either to the forward or to the reverse position, as indicated in Fig. 26 (*c*). For the forward position, finger *8* is active, and for reverse position, finger *0* is active. The coiled spring at the bottom of the case, Fig. 26 (*a*), serves to return the controller handle to off-position in case of emergency.

C-40-A CONTROLLER CAR-WIRING DIAGRAM

64. A car-wiring diagram for the alternating-current operation of two C-40-A master controllers connected to four motors is shown in Fig. 27. The system is duplex; that is, the control circuit, the compensator, and the contactors are distinct with each pair of motors.

A small autotransformer, which is shown near the oil switch, provides current for the operating coil of the switch. One end of the secondary coil of this transformer is grounded near the transformer, and the other end is grounded through *10–10A–10A–10A*–switch–*10B–10B–10B*–operating coil–*G*. When switch *10–10A* is closed, the operating coil of the oil switch closes the oil switch, and currents flow through the

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two compensators to ground. When the oil switch closes, the interlock under it opens, and the operating coil is now grounded through six high-resistance tubes. Just sufficient current flows to allow the operating coil to retain the switch in its closed position and yet not cause heating of the coil.

Wires are numbered or lettered alike at points where they enter and leave the cable hose. The action of controller No. *1* will be considered with the reverse cylinder, located at the top of the controller, at forward position; that is, with finger *8* in contact with its segment. The currents for the control circuits are obtained from taps *6* of the two compensators through the two knife switches shown at the left of the group of switches. The wires of the control circuit are indicated by red lines, and the wires of the power circuit, by black lines.

65. First Point.—On the first point, current flows from the master-controller switch to finger *T*, thence to the two drum segments, finger *a*, and to the lower right-hand finger of the reverse cylinder. Two lower reverse cylinder fingers are shown in Fig. 27, but in the actual controller only one finger *rf*, Fig. 26 (*b*), is employed. From the reverse cylinder, Fig. 27, the current path for the control of one set of motors is as follows: Finger *8*–wire *8*–connection box No. *1* –cut-out switch–*8*–*8*–interlock below the operating coil of contactor *9*–*8A*–interlock below the operating coil of contactor *11*–*8B*–operating coils of contactors *8* and *10* in parallel, and thence to the common ground wire *G*.

From finger *a*, current also flows to finger *b*–finger *1*–connection box No. *1*–cut-out switch–*1*–*1*–operating coil of contactor *5*–*1A*–upper interlock of switch *6*–*1B*–interlock of switch *7*–*G*. From finger *7*, current flows through connecting box No. *1*–*7*–*7*–operating coil of contactor *4*–*7A*–interlock of switch *3*–ground wire *G*. The main switches *4*, *5*, *8*, and *10* are closed by the action of their operating coils. Compensator tap *T1* is connected to contactor *5*.

In Fig. 28, the paths of the currents in the control circuit are indicated by red lines, while the path of the current in

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the power circuit for a set of two motors is indicated by black lines.

The two motor armatures are permanently connected in series, the compensating motor windings are connected directly in series with the armatures, and the fields of the two motors are connected in parallel. As the controller is operated, the same action is taking place in the one set of motors as in the other.

66. First Intermediate Position.—Soon after leaving the first point, Fig. 27, finger *1* drops contact, and at the same time finger *2* makes contact. When fingers *1*, *2*, and *7* are all active for an instant, contactors *5*, *2*, and *4* are closed. The motors are still connected to tap *T1* by contactors *5* and *4*, but taps *T1* and *T2* are bridged by section *c* of the rheostat. When finger *1* drops its contact, contactor *5* opens, thus cutting out tap *T1*, and allowing all the current to flow through the tap *T2*–contactor *2*–section *c* of the rheostat–contactor *4* and wire from the center of the rheostat, to the motors.

67. Second Point.—Finger *7* drops contact and finger *6* makes contact with the drum segments. Contactor *4* opens and contactor *3* closes, thus cutting out section *c* of the rheostat. The motors are now connected directly to tap *T2*.

68. Second Intermediate Position.—Finger *2* drops contact, and finger *3* makes contact. Contactor *2* opens, and contactor *6* closes. At the instant that both contactors *2* and *6* are closed, section *d* of the rheostat is bridged across taps *T3* and *T2*. When contactor *2* opens, all the current flows from tap *T3* through section *d* of the rheostat to the motors.

69. Third Point.—Finger *6* drops contact, and finger *7* makes contact. Contactor *3* opens and contactor *4* closes, thus short-circuiting resistance section *d* and leaving the motors connected directly to tap *T3*.

70. Remaining Points.—The connections of the devices in the control circuits and the motor connections for

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the remaining points and intermediate positions are shown in Fig. 28. When moving through the intermediate positions, a rheostat section is shunted across two compensator taps; then, the lower voltage tap is dropped, and the resistance section is left in circuit. Finally, this resistance is short-circuited, and the motors are left connected directly to the high-voltage tap, when the controller movement to a full point is completed. On the **fifth point,** the maximum voltage is impressed on the motors, as motor tap *T5* is active.

71. Operation of Reverse Cylinder.—When the reverse cylinder on the master controller, Fig. 27, is thrown to the reverse position, contactors *8* and *10* are opened, and the lower left-hand reverse-switch finger is connected to finger *0*–wire *0*–connection box No. *1*–*0*–*0*–interlock below the operating coil of contactor *8*–*0A*–interlock of switch *10*–*0B*–operating coils *9* and *11* in parallel–*G*. Contactors *9* and *11* are closed. The connections of the armatures remain unchanged, but the field connections have been reversed, as is shown by the fifth reverse point, Fig. 28. Motor rotation is therefore reversed.

LATER TYPE C-40-A CONTROLLER CAR-WIRING DIAGRAM

72. In Fig. 29 is shown a car-wiring diagram for two C-40-A controllers and four motors for alternating-current operation. The connections indicated in this figure are to a certain extent similar to those shown in Fig. 27, but they differ somewhat because of the method used to excite the compensating coils and to vary the electromotive force applied to the main field coils and armatures. The oil switch is closed in the manner explained in connection with Fig. 27. The interlocks of the oil switch are, however, omitted in Fig. 29.

73. First Point.—On the first point, Fig. 29, current flows from the transformer tap *T5A*–double-throw switch–master-controller switch–blow-out coil–finger *T*–drum segments–finger *a*–forward finger *8* on reverse switch–wire *8*–

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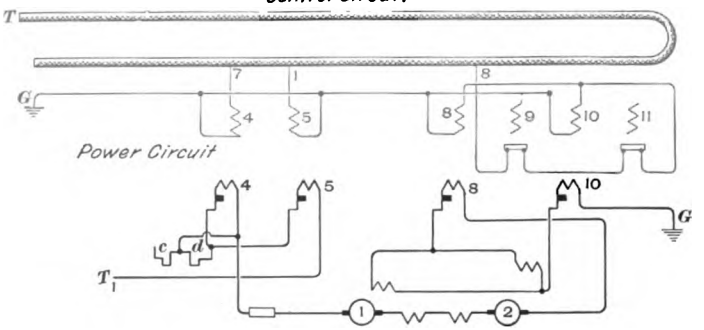
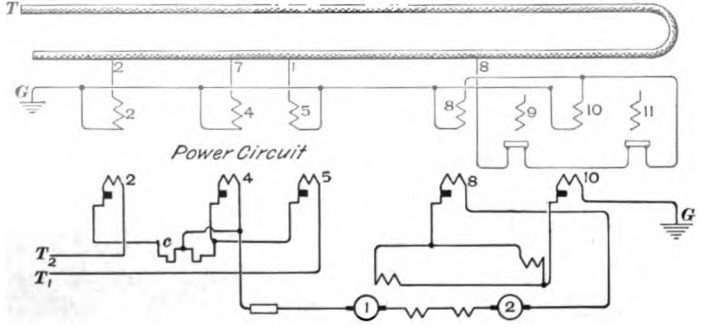
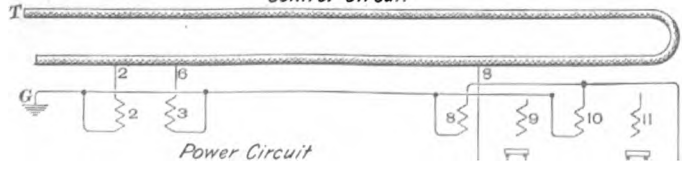
1ST POINT
Control Circuit



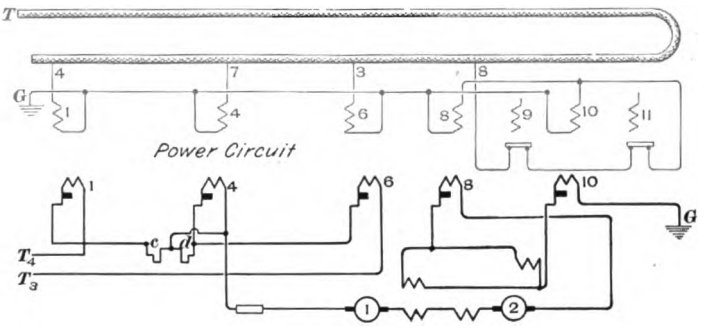
1ST INTERMEDIATE POSITION
Control Circuit



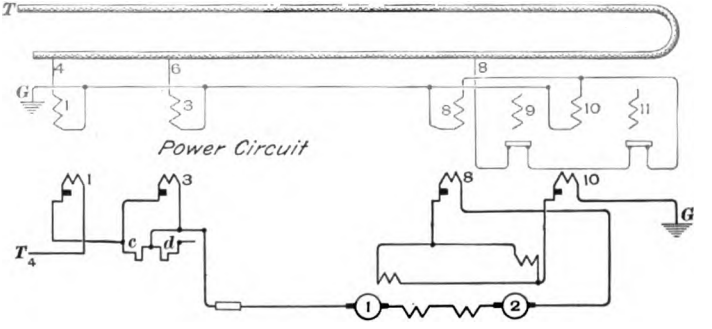
2D POINT
Control Circuit



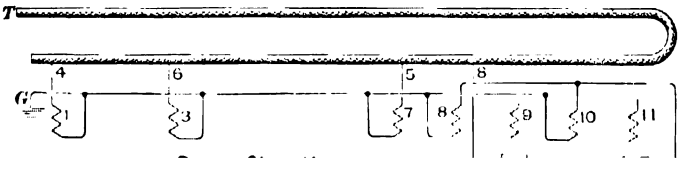
3D INTERMEDIATE POSITION
Control Circuit



4TH POINT
Control Circuit



4TH INTERMEDIATE POSITION
Control Circuit



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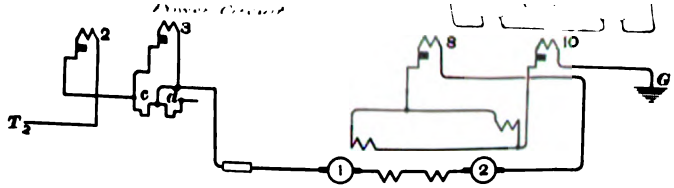
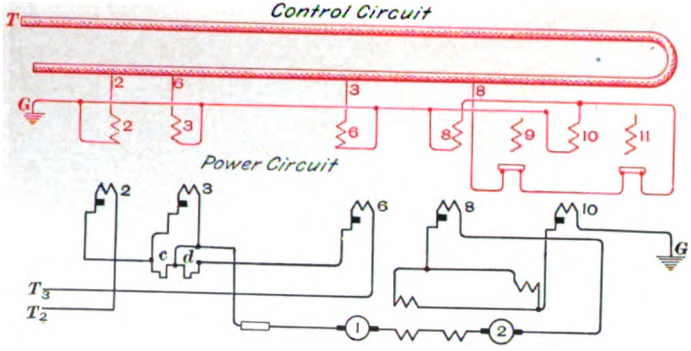
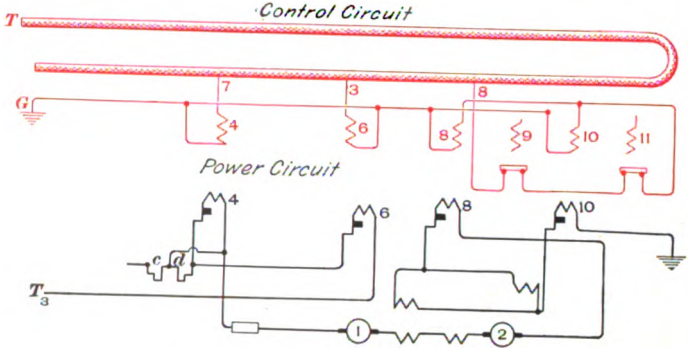
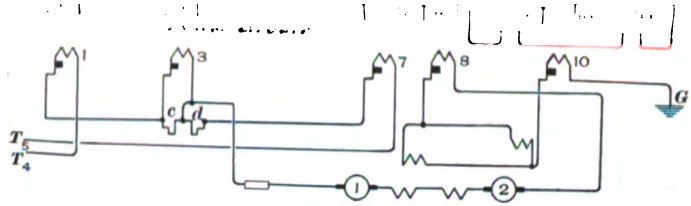


2º INTERMEDIATE POSITION

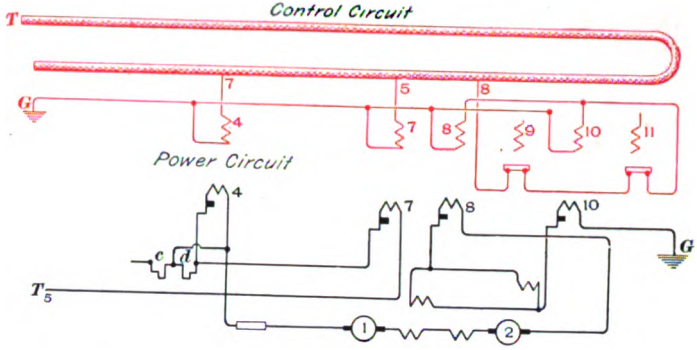


3º POINT





5TH POINT



5TH POINT REVERSE SWITCH AT REVERSE POSITION

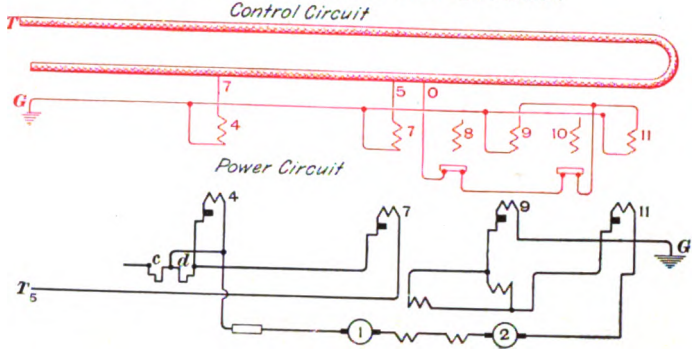


FIG. 28

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interlock over contactor *9* on left-hand switch group–*8A*–interlock over contactor *11*–*8B*–operating coils of contactors *8* and *10* in parallel–*OR*–*OR*–*G* at overload relay. Contactors *8* and *10* close.

Current also flows through fingers *T* and *a*–wire *1*–operating coil of contactor *7*–*1A*–*1A*–*G* at motor switch. Contactor *7* closes.

Wire *2* is connected to two fingers, as shown. Current flows from the upper one of these fingers–wire *2*–operating coil of contactor *2*–*G*. Contactor *2* closes. The paths of the current in the control circuit and motor circuit are indicated in Fig. 30. The compensating coils are connected between tap *T1* and the ground, and the armatures and main-field coils of the motors are connected between taps *T2* and *T1*. A section of the rheostat is included in the motor circuit.

74. First Intermediate Position.—The connections for the first intermediate position are the same as those indicated in the first position, Fig. 30.

75. Second Point.—Finger *6* and contactor *3*, Fig. 29, are now active, and the rheostat section is cut out of circuit, thus increasing the electromotive force applied to all the motor windings except the compensating windings. The compensating windings are connected between tap *T1* and the ground for all active positions of the controller, as shown in Fig. 30.

76. Remaining Points.—The connections of the more important devices in the control circuits and the motor connections for the remaining points and intermediate positions are shown in Fig. 30. When moving through the intermediate positions, a rheostat section is shunted across two compensator taps; then, the lower voltage tap is dropped, and the resistance section is left in circuit. Finally, this resistance is short-circuited, and the motors are left connected between the high-voltage tap and tap *T1*, when the controller movement to a full point is completed. On the **fifth point**, the maximum voltage is impressed on the motors, as tap *T5* is then active.

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When the reverse cylinder, Fig. 29, is at the reverse position and the power drum is at the fifth point, reverse finger *0* and contactors *9* and *11* are active. The connections of the main field coils are reversed, and the motors rotate in the opposite direction to their former direction of rotation. The connections are indicated in Fig. 30.

77. Overload Relay.—The operating coils of contactors *8*, *9*, *10*, and *11*, Fig. 29, which control the main field and armature connections, form their ground connection through wire *OR* and the upper interlock of the overload relay. If the ground connection of the operating coils of these contactors is broken, these contactors will open. If the motor current becomes larger than that for which the overload relay is adjusted, the relay coil in the motor circuit will pull up its armature and thus break the ground connection for wire *OR* and form a ground connection through the lower interlock for the relay holding coil. This coil is furnished with current from wire *1*. Since wire *1* is active at all points of the controller, the controller must be turned to off-position before the holding coil can become deenergized and wire *OR* can again be grounded. The controller can then be operated provided normal conditions of motor current obtain.

78. Speed-Limit Relay.—The operating coil of the speed-limit relay, Fig. 29, is connected across the terminals of the field coils of the motors. Normally, the relay interlock is closed when the field coils are excited, and this interlock forms a ground connection for wire *SR* and for the operating coils of contactors *1*, *5*, and *6*, that control taps *T4*, *T5*, and *T3*. When the car is running at excessive speed, with the power on, as, for instance, on a down grade, the counter electromotive force is high and the current through the field coils is low. Under these conditions, the current through the operating coil of the relay is also much below normal, and the relay armature drops, thus opening the ground connection of wire *SR*. If this action occurs on the fifth forward point, contactor *5* will open. Contactors *4*, *7*, *8*, and *10* will remain closed, because the ground con-

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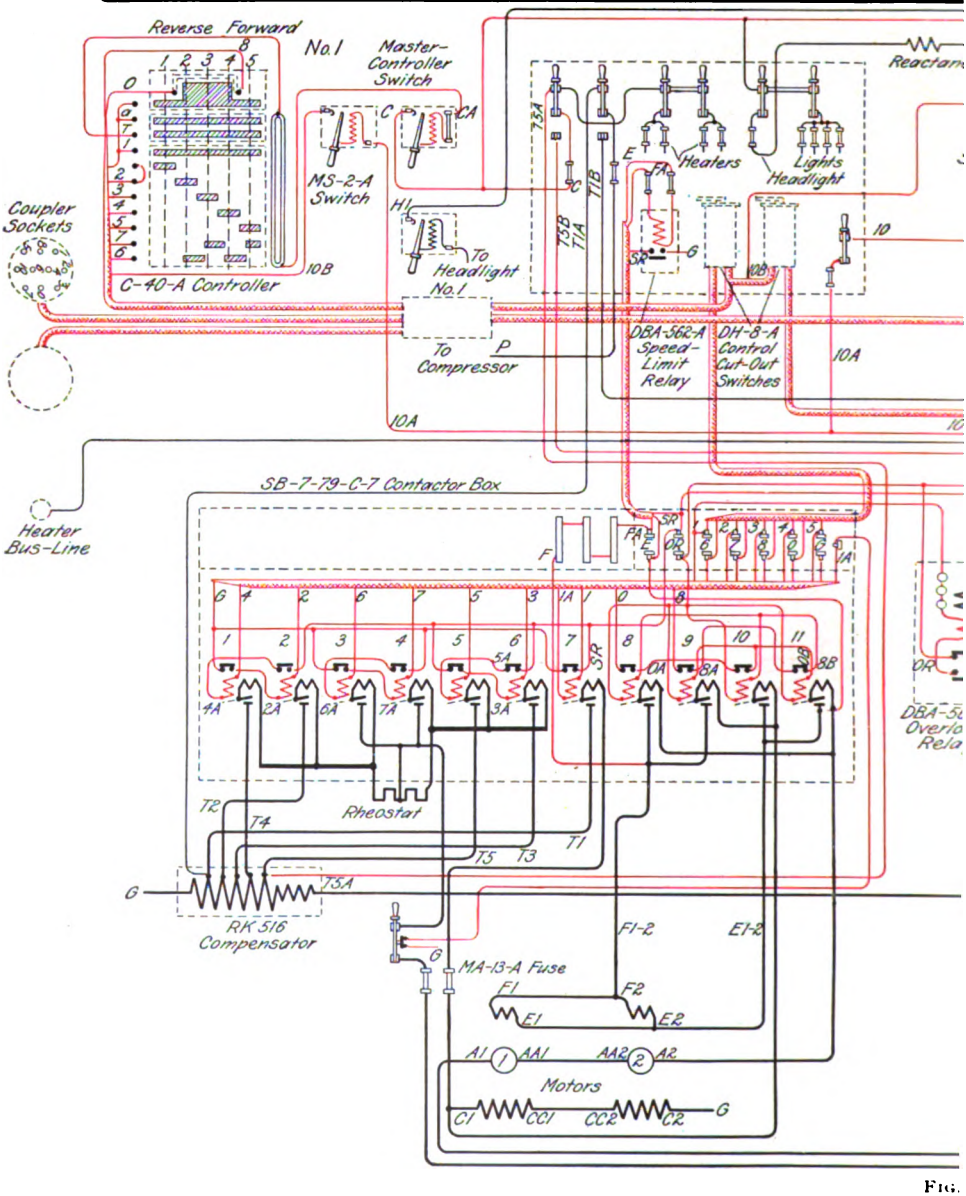

FIG.

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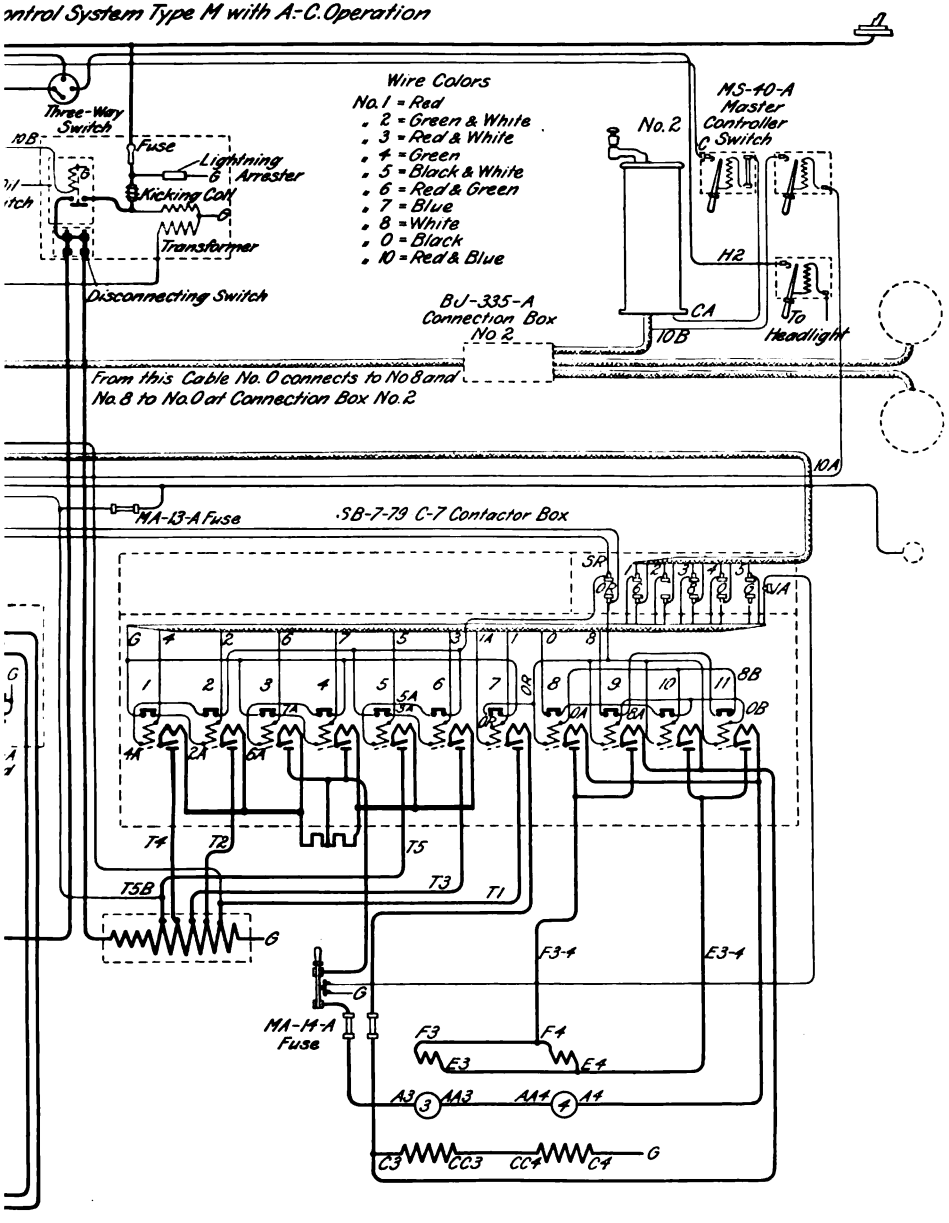

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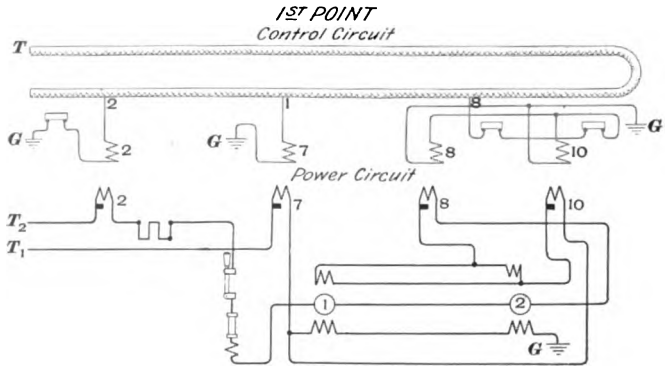

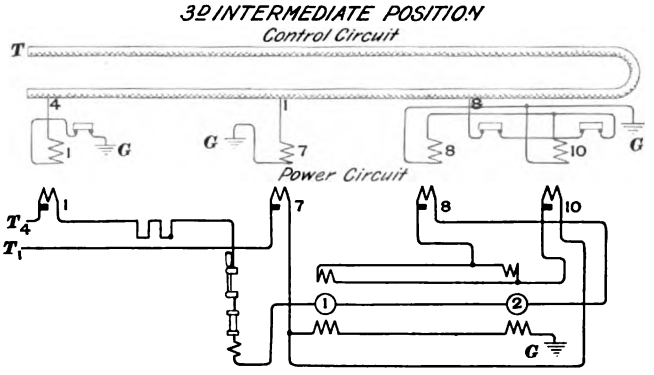

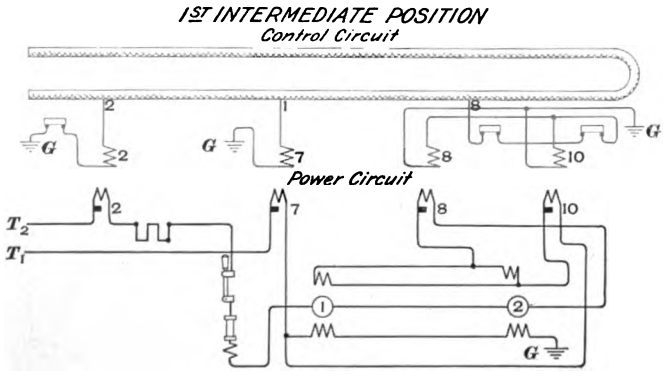

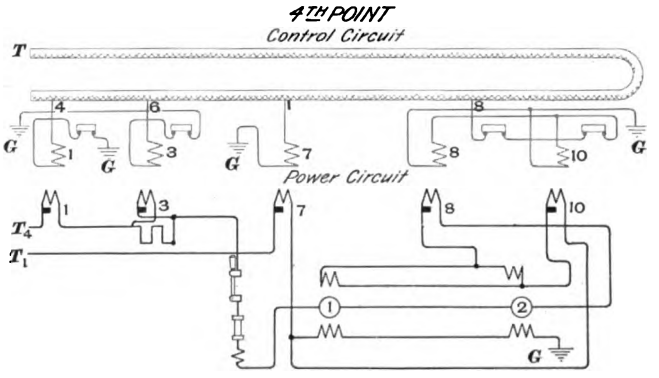

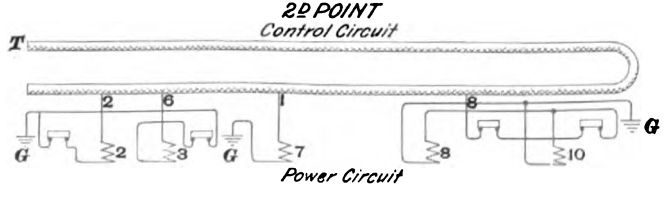

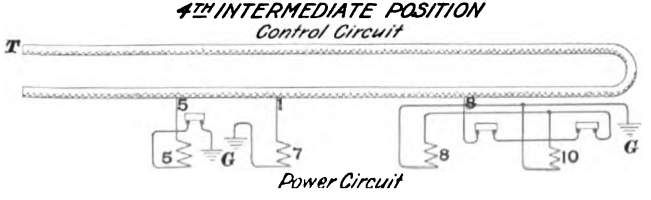

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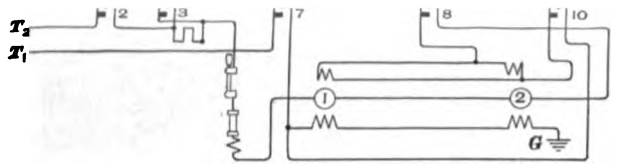
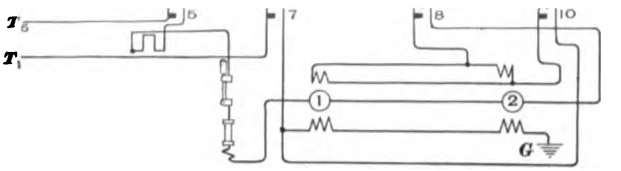
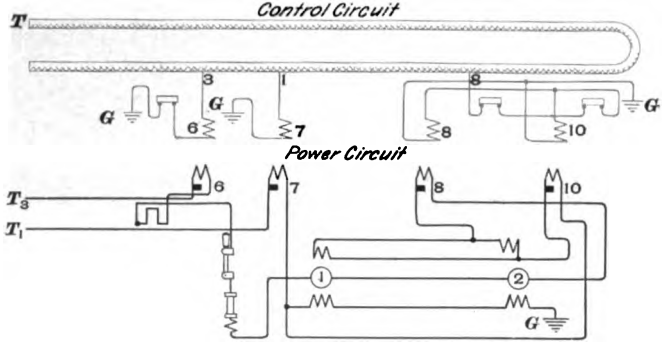
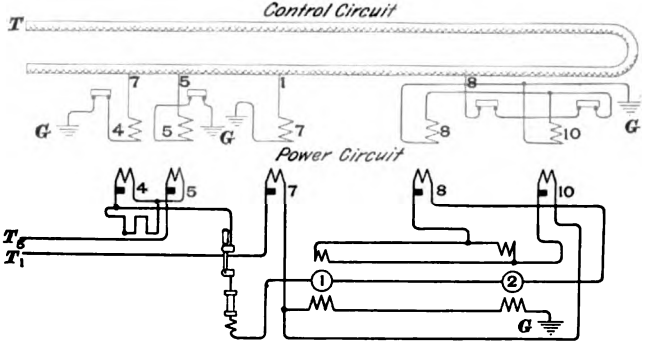




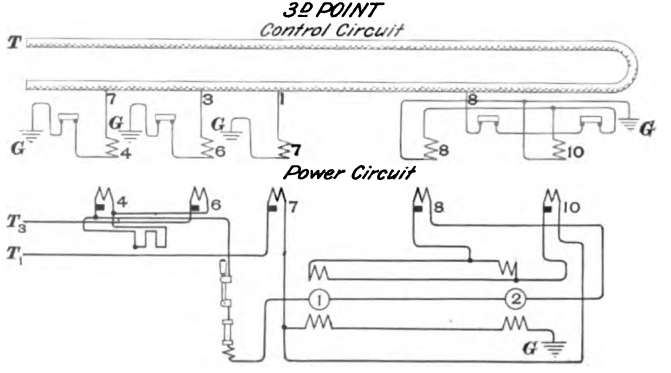
2D INTERMEDIATE POSITION



5TH POINT



3D POINT



5TH POINT, REVERSE SWITCH AT REVERSE POSITION

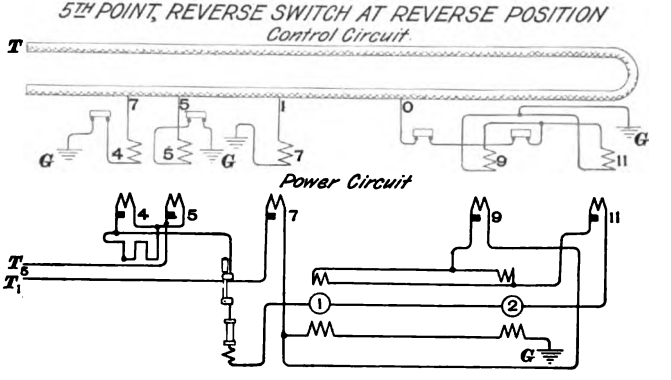


FIG. 30

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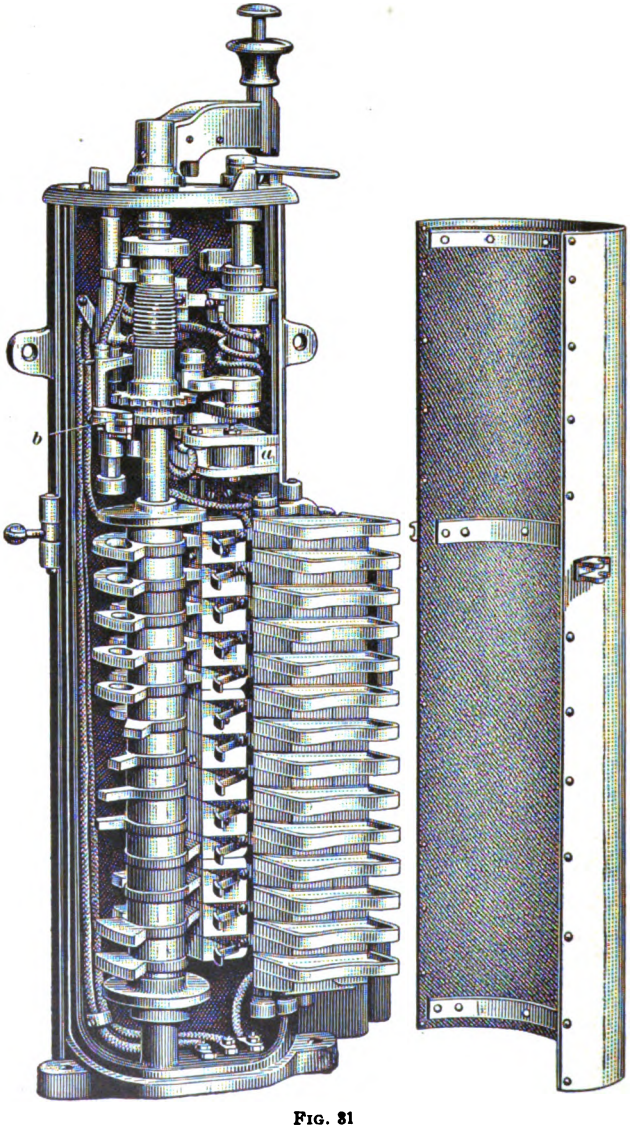

FIG. 31

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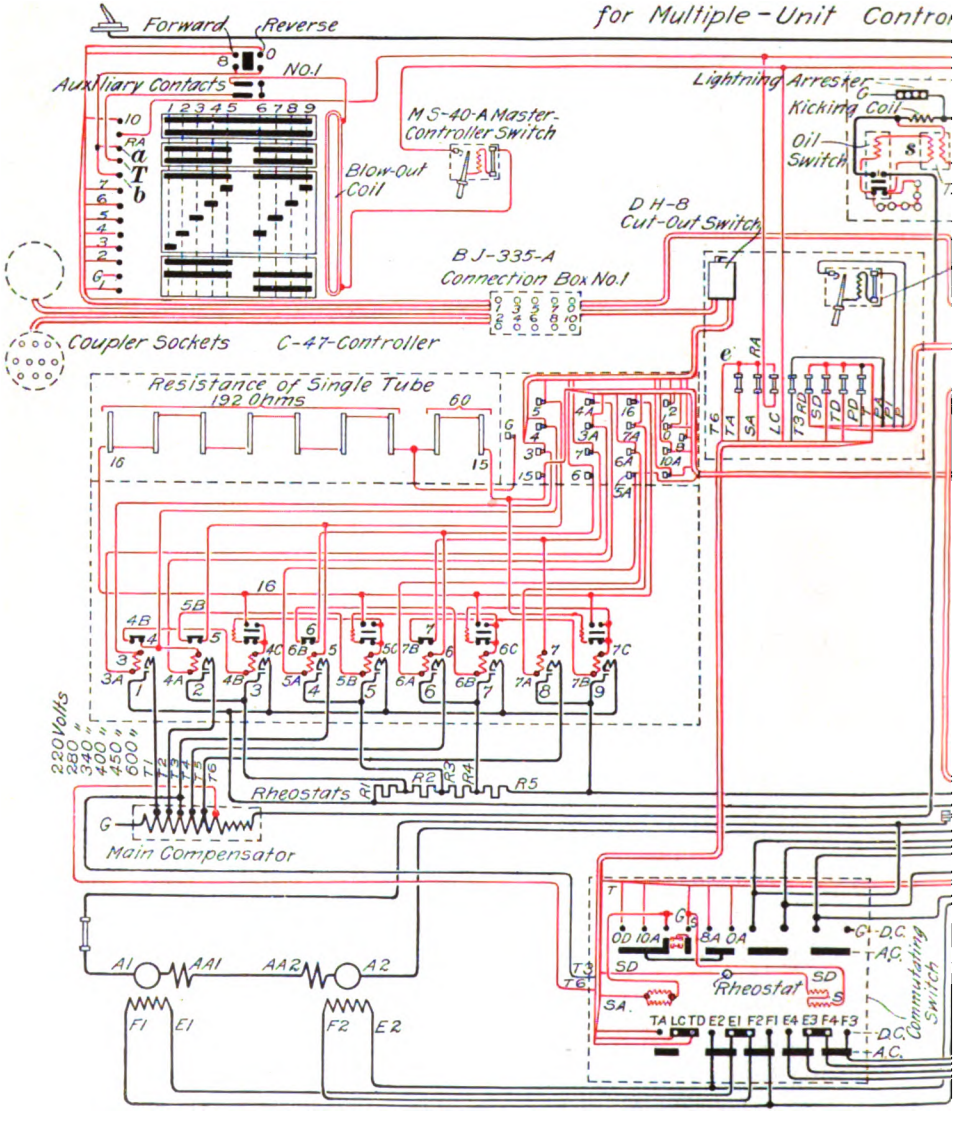

FIG.

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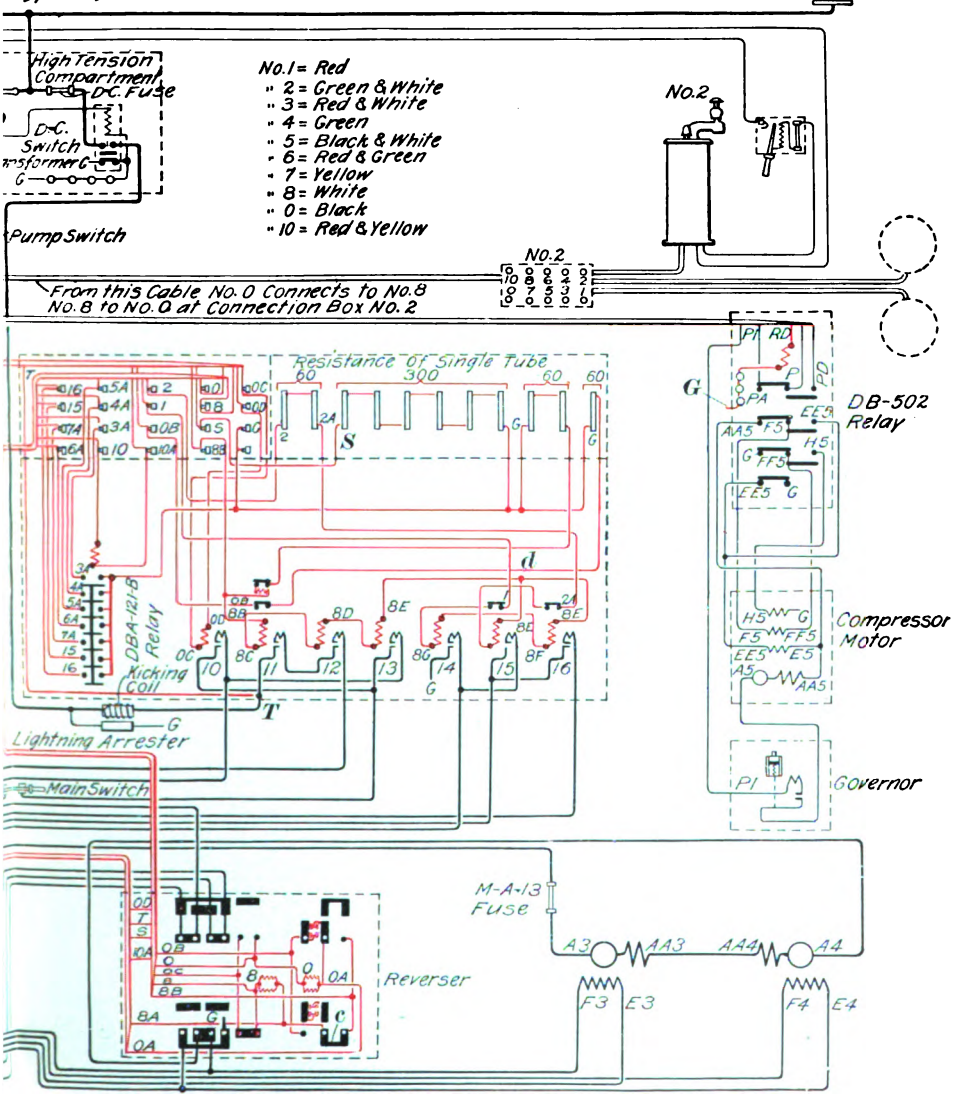
DIAGRAM

Type M, A.C. and D.C.



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C-47 CONTROLLER FOR ALTERNATING-CURRENT AND DIRECT-CURRENT CONTROL

80. In Fig. 31 is shown a **C-47 master controller.** This controller has auxiliary contacts *a* that open the control circuit in case the knob on the controller handle is released. A trip lever *b* is also provided. This lever will open the auxiliary contacts when the handle is moved toward the off-position. The handle must be returned to off-position before the controller can be operated to pick up the contactors again.

C-47 CONTROLLER CAR-WIRING DIAGRAM

81. A car-wiring diagram of two C-47 controllers connected to four motors, for operation by either direct or alternating current, is shown in Fig. 32. When direct current is to be used, the direct-current switch is automatically closed by the operating coil on the switch. Direct current flows from the trolley, through the kicking coil–primary coil *p*–operating coil of the *D.-C.* switch–interlock, which is closed when the *D.-C.* switch is open, to the ground at *G*. As the switch closes, the ground connection at the interlock is broken, and current now flows to ground through the four high-resistance tubes. The reduced current prevents heating and is sufficient to retain the switch in its closed position. The direct current flowing through primary coil *p* has no effect on the secondary coil *s* and the operating coil of the alternating-current switch. If the line electromotive force becomes very low, the operating coil releases and opens the direct-current switch.

If the commutating switch rests in the *A.-C.* position, current for the control circuit of the commutating switch flows from the trolley–*D.-C.* fuse–*D.-C.* switch–*D.-C.* kicking coil–junction *T* near lower connection of contactor *11*–*T*–*T* near reverser–*T* near commutating switch–up through cable–*T*–*SD*–*SD*–rheostat–*SD*–*D.-C.* operating coil of the commutating switch–*S*–*S*–to ground through the *A.-C.* commutating-switch segments and finger *G*. The commutating switch is

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thrown to its direct-current position. If the switch is in the *D.-C.* position, the path to ground is from finger *S* of the commutating switch–*S*–*S*–*S*–six high-resistance coils–*G*.

Current for the master controller flows from the lower portion of contactor *11*–*T*–*T*–*T*–*T*–up through cable–*T*–*TD*–*TD*–*D.-C.* segment–*LC*–*LC*–master-controller switch–blow-out coil–auxiliary contacts–finger *T*.

82. Direct-Current Operation.—When using the C-47 controller for direct-current operation, all of the nine controller points are employed.

From finger *T* on the **first point**, Fig. 32, current flows along the following path: Finger *T*–drum segments–*a*–forward finger *8* on the reverse cylinder–*8* on connection box No. *1*–*8*–*8*–*8*–*8*–forward operating coil of the reverser, thus throwing the reverser to forward position if it was at the other position–fingers on segment *c*–*8B*–*8B*–the current divides, part of it flows through the upper interlock over contactor *11*–two resistance tubes–*G*, and part through *8B*–operating coil of contactor *11*, which opens the interlocks above it, thus interrupting the first path to ground–*8C*–operating coil of contactor *12*–*8D*–operating coil of contactor *13*–*8E*–*d*–*8E*–operating coil of contactor *15*–interlock over contactor *16*–*2A*–*2A*–two high-resistance coils–*2*–*2*–*2*–*2* on connection box No. *1*–finger *2* on the master controller–ground at finger *G*.

From point *d* current cannot flow through the operating coils of contactors *16* and *14*, because finger *1* on the controller hangs in the air; also, the interlock over contactor *15* opens when contactor *15* closes. The reverser is thrown to its forward position, and contactors *11*, *12*, *13*, and *15* are closed.

The operating coil of the relay, near the right-hand group of contactors, is connected to controller finger *10*, which is active only for alternating current. Thus, the relay is open when direct current is used, so that no current can flow from finger *T*–*a*–*b*–*3*–*3* on connection box No. *1*–*3*–*3*–operating coil of contactor *1*–*3A*–*3A*–*3A*–finger *3A* of relay,

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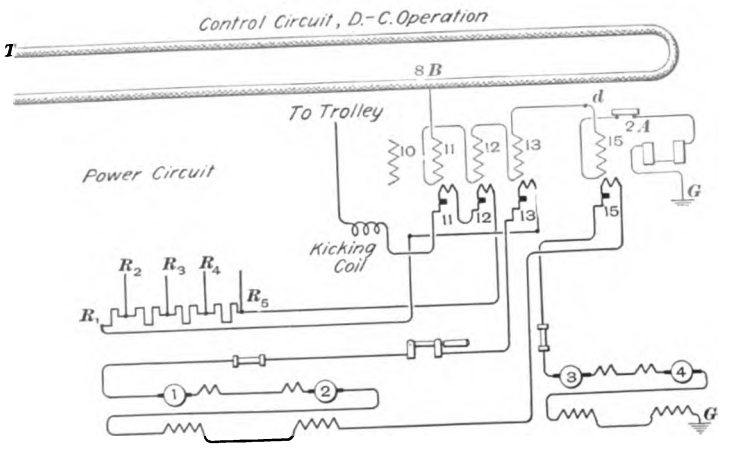
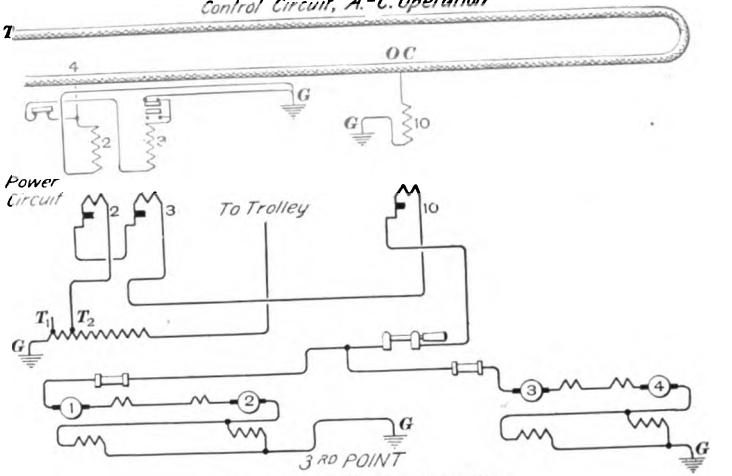
1ST POINT

Control Circuit, D.-C. Operation



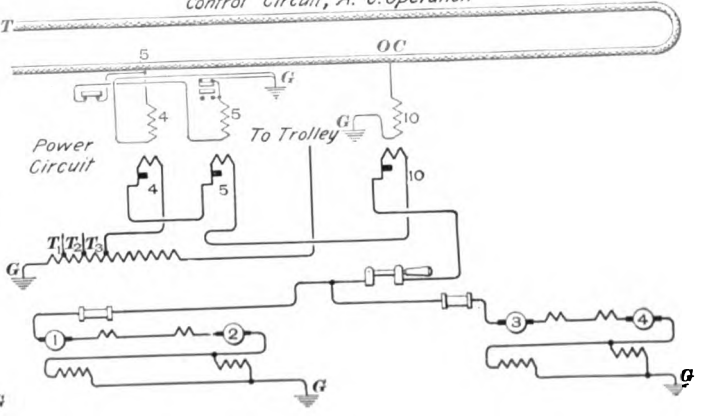
2ND POINT

Control Circuit, A.-C. Operation



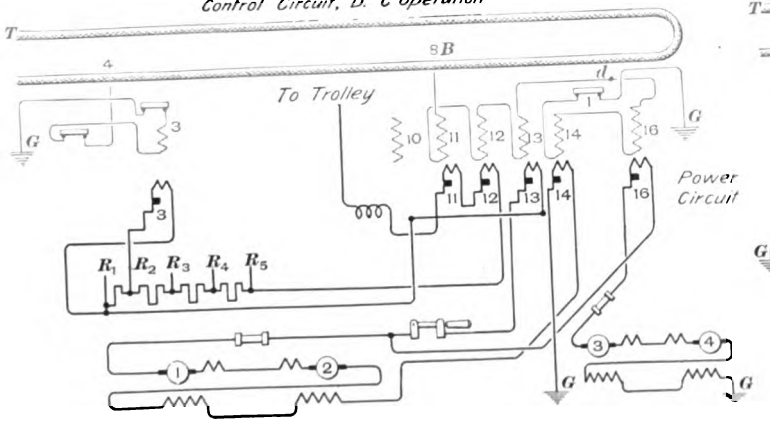
3RD POINT

Control Circuit, A.-C. Operation



6TH POINT

Control Circuit, D.-C Operation



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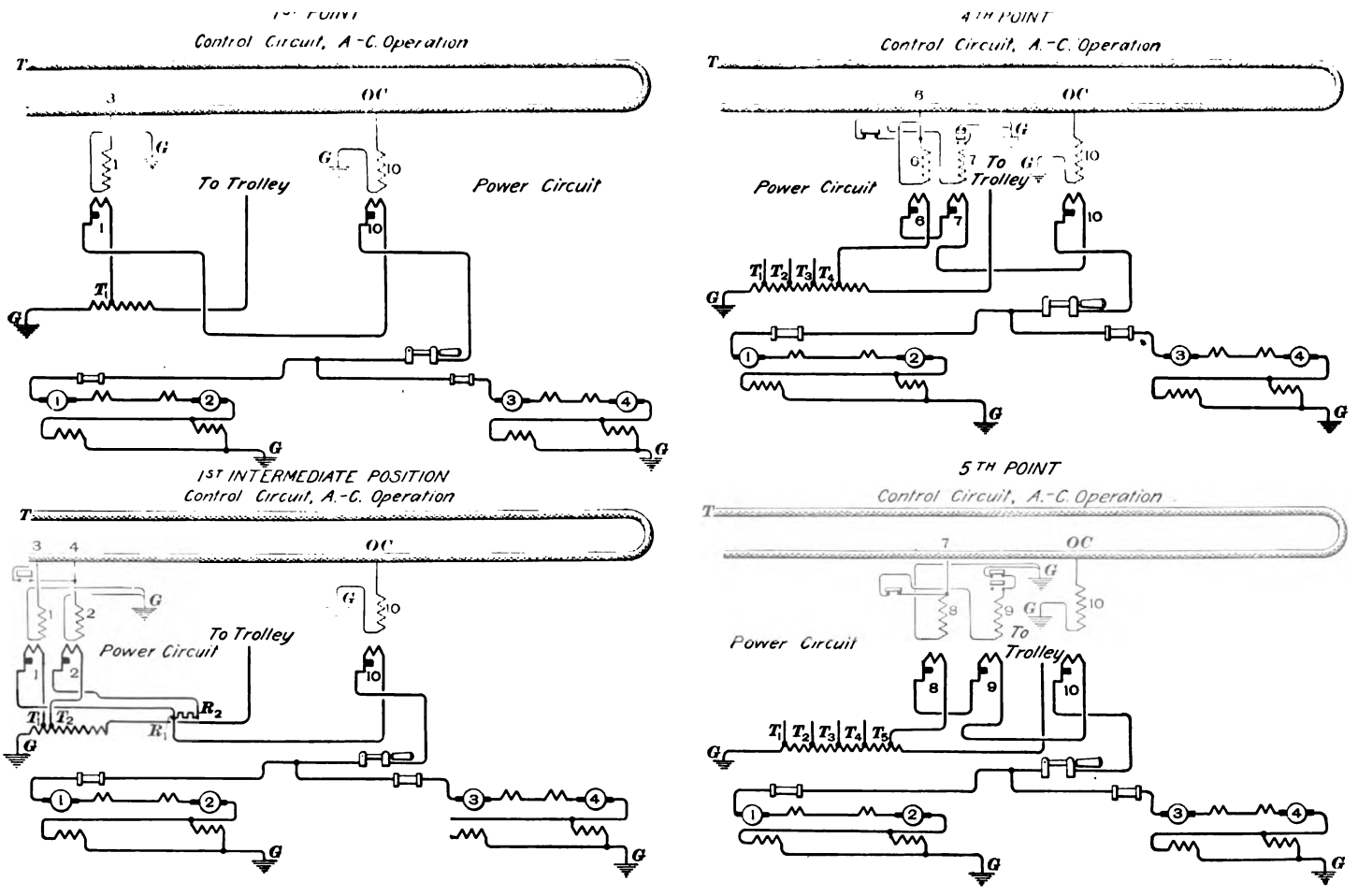

FIG. 33

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because of the open circuit at the relay. The connections of the operating coils, the contactors, and the motors are shown in Fig. 33.

83. On the **second point,** finger *4*, Fig. 32, makes contact with its drum segment. The current path is: finger *4–4* on connection box No. *1–4–4* (current cannot flow to the right because of the open circuit at the relay)–interlock over contactor *1–4B–4B*–operating coil of contactor *3–4C*–at first lower interlock of switch *3*–interlocks of switches *5*, *7*, and *9* to *15*–two resistance tubes to ground, and then an instant later to ground by the upper interlock over contactor *3* when contactor *3* closes–*16*–seven resistance coils–*G*.

Contactor *3* is closed, and the rest of the contactors remain as before. Current can now flow from resistance lead *R2*, through contactor *3*, to the main motor switch. The section of resistance between *R1* and *R2* is cut out.

On the **third point,** finger *5* makes contact with its drum segment. Contactor *5* is closed, and resistance sections *R1–R2* and *R2–R3* are cut out.

On the **fourth point,** finger *6* makes contact with the drum segment. Contactor *7* is closed. Resistance sections from *R1* to *R4* are cut out.

On the **fifth point,** finger *7* becomes active, and contactor *9* closes. All the resistance sections are cut out, and the motors are in series across the line.

On the **sixth point,** finger *2* drops its contact, and finger *1* makes contact with its drum segment. Contactor *15* opens and its interlock closes. Current flows from finger *T* on the controller to junction *d*, over contactor *15* by the same path traced for the first point. From point *d*, near contactor *15*, current now flows to *8E*–operating coil of contactor *16–8F*–operating coil of contactor *14–8G*–interlock *1–1–1–1* on connection box No. *1*–finger *1*–drum segment–*G*. Current cannot flow from *d* through the operating coil of contactor *15*, because finger *2* hangs in the air and interlock *2A* is open.

Contactors *14* and *16* are closed, and contactor *15* is opened. Finger *4* is active, and contactor *3* is closed.

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The two sets of motors are in parallel with three sections of resistance in series with them, as indicated in Fig. 33.

On the **seventh, eighth, and ninth points,** Fig. 32, one section of resistance is cut out on each point in the same manner as on the third, fourth, and fifth points. On the ninth point, the two sets of motors are in parallel across the line, without any resistance sections in series.

84. Alternating-Current Operation.—When using the C-47 controller for alternating-current operation, the first five controller points are employed.

On the **first point,** Fig. 32, the alternating-current oil switch is automatically closed by the operating coil on the switch. The direct-current switch is opened automatically as the trolley passes over the line breaker that separates the alternating- and direct-current line wires. The direct-current switch interlock is closed, and an alternating current at a pressure of about 3,300 volts flows through the primary coil *p*, the operating coil of the direct-current switch, directly to ground through the direct-current interlock. The alternating current in *p* sets up an alternating current in *s* and in the operating coil of the alternating-current switch. The resistance and the impedance of the operating-coil circuits are so adjusted that the system is selective. The direct-current switch is thrown in when the trolley is on the direct-current wire, and the alternating-current switch is thrown in when the trolley is on the alternating-current trolley wire. When the alternating-current interlock opens, a resistance is introduced into the secondary circuit to prevent the operating coil from heating. Current flows from the trolley–kicking coil–*A*.-*C*. oil switch–main compensator to ground at *G*.

From compensator tap *T6*, current flows to *T6*–*T6*–point *e* –*SA*–*SA*–*A*.-*C*. operating coil of the commutating switch –ground at *G*. The commutating switch is thrown so that the fingers make contacts with the alternating-current segments.

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At point *e*, current flows to *TA–TA–A.-C.* segment of commutating switch–*LC–LC*–master-controller switch–blow-out coil–auxiliary contacts–finger *T*.

From *e*, current also flows to *RA* and to controller-drum finger *RA*. From this finger, the path of the current, when the controller drum is active, is as follows: *RA–10–10* on connection box No. *1–10A–10*–operating coil of the relay–*10A–10A–10A–A.-C.* segment of commutating switch–*G*. The relay rises, and its metal portions make contacts with all its fingers. The fingers on the right side of the relay are connected to the ground, so that all the other fingers have a ground connection when the relay is active. Current from drum finger *T* flows to finger *8* on the controller reverse switch–*8* on the reverser–reverser segment–*0C–0C–0C*–operating coil of contactor *10–0D–0D–0D–0D–G*. Contactor *10* closes.

From *8* on the reverser, another path is as follows: *8*–forward reverser coil–*8A*–finger *8A* on the commutating switch–*A.-C.* segments–ground. The path through segment *c–8B*–operating coils of contactors *11*, *12*, *13*, and *15* is short-circuited by the path through *8A*; therefore, contactors *11*, *12*, *13*, and *15* open. The reverser is still at forward position. Another path from finger *T* on the master controller, when the drum is at the first point, is: *T–a–b–3–3* on connection box No. *1–3–3*–operating coil of contactor *1–3A–3A–3A–3A*–relay–*G*. Contactor *1* closes.

The sets of motors are connected in parallel by means of the alternating-current segments of the commutating switch. The main field coils of each pair of motors are connected in parallel, but the two armatures are connected in series. The connections of the control and power circuits are shown in Fig. 33, at the first point, alternating-current operation.

On the **first intermediate position,** before controller finger *3*, Fig. 32, breaks contact with its drum segment, finger *4* makes contact with its segment. As contactor *1* is still closed at the intermediate position, its interlock is open. Current flows from finger *4* to point *4* between contactors *1* and *2*. Current cannot flow to the left because of the open

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interlock, but it can flow through the operating coil of contactor *2* to the ground through the relay.

Contactor *2* closes, and the first resistance section is shunted across compensator taps *T1* and *T2*, as indicated in Fig. 33, at the first intermediate position. The motor circuit is connected to side *T1* of the resistance section.

85. On the **second point,** as soon as controller finger *3*, Fig. 32, drops its drum contact, contactor *1* opens and its interlock closes. Current now flows from point *4* to the left, through the interlock of contactor *1*, and then through the operating coil of contactor *3* to the ground, first by way of the lower interlock–wire *15*–relay–ground, and shortly afterwards by way of the upper interlock–wire *16*–relay–ground. These circuits are now grounded through the alternating-current relay, because that path offers less resistance than the path through the high-resistance tubes.

Contactor *1* opens just before contactor *3* closes, owing to the action of the interlock over contactor *1*. For a short time, current flows from *T2*, through the first section of resistance, to the motor circuit. Immediately after, contactor *3* closes and a direct path is provided to the main motor switch, thus short-circuiting the resistance section. This condition is indicated in Fig. 33 at the second point.

86. On the **third, fourth,** and **fifth points,** Fig. 32, higher-voltage taps are successively connected to the motor circuit. During the passage of the controller drum through the intermediate positions, the different sections of the main resistance coil are used to shunt sections of the compensator in a similar manner to that described in connection with the first intermediate position. On the fifth point, contactors *8*, *9*, and *10* are closed, and the two sets of motors in parallel are connected between the high-voltage tap *T5* and the ground. The controller should not be advanced beyond the fifth point for alternating-current operation.

87. Operation of the Compressor Motor.—With direct-current operation, current flows through control wire *T*, Fig. 32–*RD*–*RD*–operating coil of the compressor-motor

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relay–three high-resistance coils, to ground at *G*. The segments of the compressor-motor relay are lifted. Current flows from *T* through *PD–PD–P–P*–pump switch, governor, and through the armature and all the main field coils in series to ground. When using alternating current, the compressor-motor relay segments are in their lower positions. Current is obtained from tap *T3*. The two lower portions of the field windings are in parallel, and the upper field-winding section is cut out.

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ELECTRIC LOCOMOTIVES

NEW YORK, NEW HAVEN, AND HARTFORD RAILROAD LOCOMOTIVE

SERVICE CONDITIONS

1. The general features of the electric installations in the electric zones of the New York, New Haven, and Hartford Railroad Company and the New York Central and Hudson River Railroad Company are described in *Transmission Systems for Heavy Traction.*

The New York, New Haven, and Hartford locomotives operate on the 600-volt, direct-current system from Grand Central Station to Woodlawn, a distance of about 12 miles, and on the 11,000-volt, 25-cycle, single-phase, alternating-current system from Woodlawn to Stamford, Connecticut, a distance of about 22 miles from Woodlawn. The locomotives are equipped with Westinghouse single-phase motors that operate on either current system.

There are two distinct classes of service that these locomotives have to perform: (1) One or two locomotives haul local suburban trains, made up of from three to twelve day coaches, between Grand Central Station and New Rochelle, Port Chester, or Stamford and intermediate stations. (2) Two or more locomotives haul through express trains, made up of from nine to fifteen Pullman cars, between Grand Central Station and Stamford.

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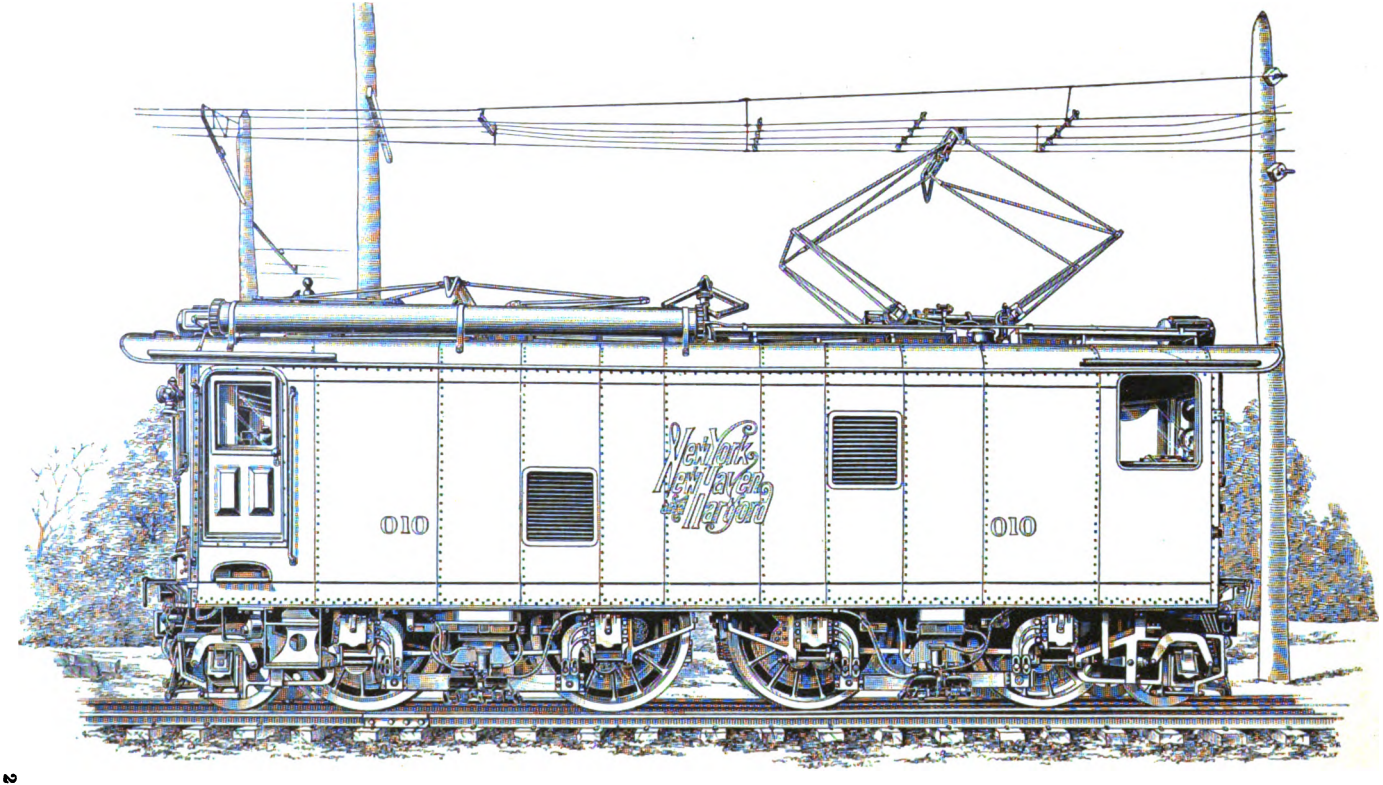

FIG. 1

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GENERAL DESCRIPTION OF LOCOMOTIVE

2. Each locomotive is made up principally of a cab, two motor trucks, two pony trucks, and the equipment. In Fig. 1 is shown a complete locomotive. In the cab is installed the control and auxiliary apparatus, and on the roof is fitted the overhead current-collecting trolleys, the whistle, the bell, etc. The two main motor trucks are fitted with four driving motors, or one motor for each axle of the trucks. Third-rail current-collecting shoes are installed on each side of the motor trucks.

3. Cab.—The cab is composed of a strong skeleton of **Z** bars and angle irons. These bars and irons are fastened together by means of gusset plates and rivets. The skeleton is covered with sheet-steel plates that are riveted to the skeleton structure. The inside of the cab is covered with cork cement, so as to keep out cold during winter.

The cab has one door at each side for the use of engineers and inspectors, and these doors are fitted with drop windows in the upper panels. At each end of the cab is a door that has a fixed window in the upper panel. All doors open inwards, so that they cannot fly open and strike objects near the track.

A window for the use of the engineer is provided in the side at each end of the cab. It is a combined sliding and drop window, and may be partly or fully opened as required. Each end of the cab is also fitted with two drop windows.

On each side of the cab are two ventilator panels that are arranged for discharging into the atmosphere the air that has been forced through the transformers and resistances for cooling purposes. The reasons for this artificial cooling, or forced ventilation, will be explained later.

4. Under Frame.—The subframe is composed of side and center channels arranged lengthwise of the locomotive. They are secured by means of cross-sills that are connected to them by riveted gusset plates and knee braces. The end

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frames are composed of heavy channels reinforced with knee braces. The whole frame is designed so as to resist most effectively the very heavy stresses that result from coupling, etc.

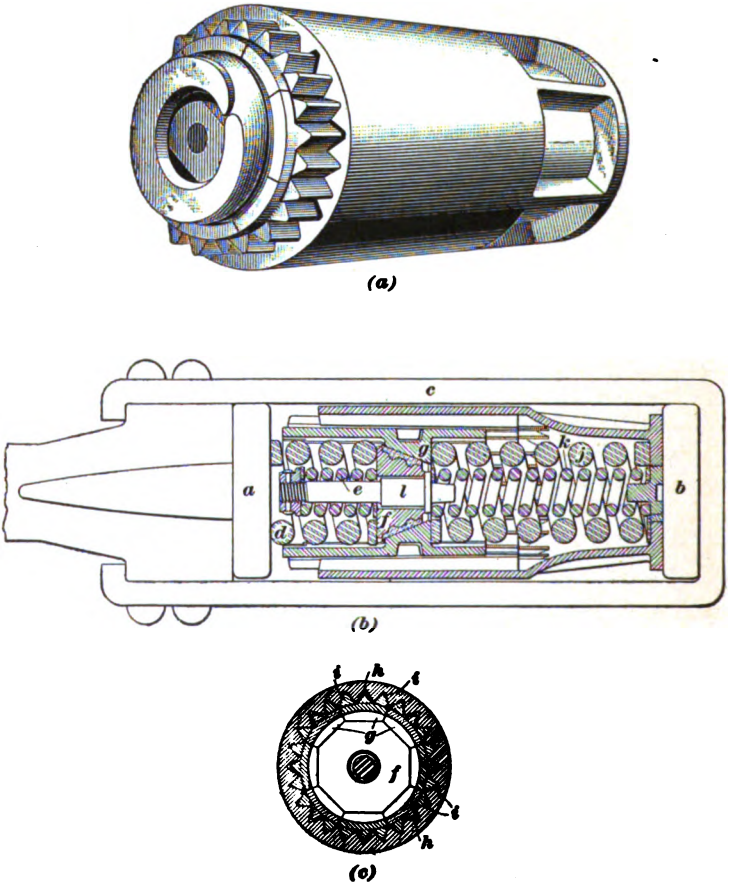

FIG. 2

5. Couplers and Draft Gear.—The couplers are, as required by law, of the automatic type. They are equipped with the Westinghouse friction draft gear, which is fitted to the longitudinal channels at the center line of the locomotive.

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The **draft gear,** as its name implies, is a device to absorb, through springs and friction strips, the shocks and jerks transmitted through the draw-heads. This device thus prevents the locomotive frame from being injured.

In Fig. 2 (*a*) is shown the gear completely assembled, but without the yoke, follow pieces, etc.; in (*b*), a longitudinal section of the gear, showing the yoke and follow pieces; and (*c*), a cross-section of the gear.

In (*b*) and (*c*), the outer follower plate is shown at *a*; the inner follower plate, at *b*; the yoke, at *c*; the preliminary spring, at *d*; and the auxiliary spring, at *e*. The wedge *f* has eight sides, which are faced with hard brass. Each of the malleable-iron segments *g* has one longitudinal rib to strengthen it and to guide the segment in groove *h*, and two friction strips that fit into grooves *i*. The main release spring is shown at *j*; the auxiliary release spring, at *k*; and the release pin, at *l*. The coupler is attached to the left-hand end of the yoke.

Follower plate *a* is prevented from moving when a pull is to be transmitted, and follower plate *b* is prevented from moving when a push is to be transmitted. Follower plate *b* is moved toward plate *a* when a pull is exerted on the coupler, and spring *d* is compressed sufficiently to allow the ends of segments *g* to press against plate *a*. Release pin *l*, which extends slightly beyond the segments, is forced back, the left-hand side of the shoulder on pin *l* moves away from wedge *f*, and the right-hand side of the shoulder takes the pressure of auxiliary release spring *k* on itself and relieves wedge *f* of the pressure of this spring. In this position, the pressures of the compressed springs *d* and *e* move the wedge to the right and force outwards the segments and their friction strips. A greater pull puts the friction strips into motion, thus causing friction between the friction strips and the grooves. The friction increases as the movement of plate *b* increases because the grooves are tapered.

When the pulling force is withdrawn, the springs *d* and *e* gradually return to their normal positions. Spring *k* pushes the wedge into its normal position, and spring *j* presses the segments and friction strips to their normal positions.

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When buffing, the action of the gear is as just described, except that follower plate *a* moves toward *b*.

6. Trucks.—As indicated in Fig. 1, each locomotive has two motor trucks and two pony trucks. A single motor

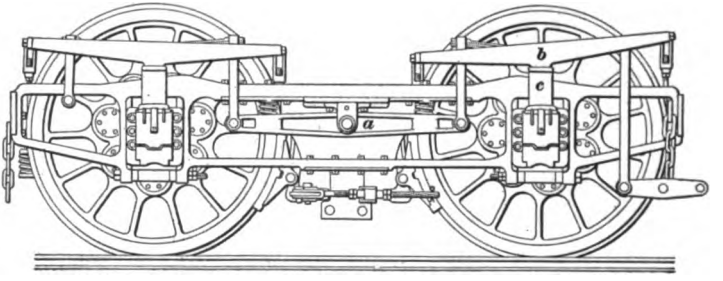

FIG. 3

truck without motors or collector shoe beams is shown in Fig. 3. A pony truck is attached to each motor truck. The side frames are of the usual engine type, and are made of cast steel. The bolster is made up of channels that are

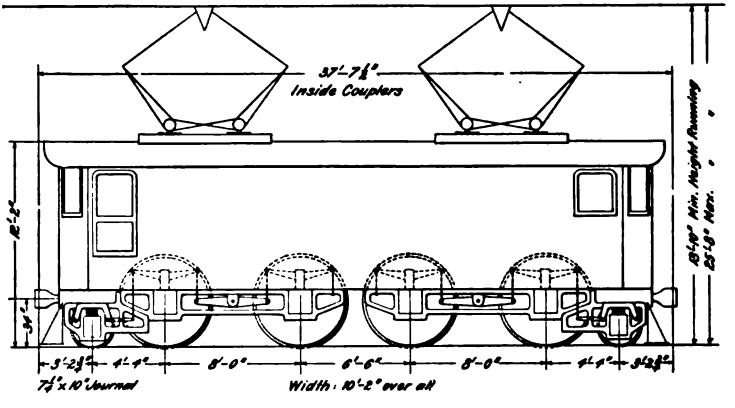

FIG. 4

reinforced with plates. The wheels have cast-steel centers and rolled-steel tires.

The weight of the cab and its equipment is transmitted through the bolster and a system of levers, hangers, and

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springs arranged so as to equalize the load between the axles of the motor trucks and the pony trucks, and yet be very stiff in resisting side motion and oscillation. This system is indicated at *a*, Fig. 3.

The yoke, shown at *b*, is a part of the motor suspension and will be described under the subject of motors, since it is strictly a part of the motor. At *c* is shown a saddle through which weight is transmitted to the axle box.

7. Dimensions.—The general dimensions of the locomotive are shown in Fig. 4. It will be noted that a minimum and a maximum height for the trolley collector are given. The reason for this is that the trolley wire, where it passes under bridges, must be much lower than normal.

8. Weight.—The weight of the locomotive complete with equipment is 101 tons. The weight at the rail head for each driving wheel is 20,000 pounds, and the weight at the rail head for each pony wheel is 10,500 pounds.

EQUIPMENT

9. The equipment comprises all the apparatus used for the following operations: (1) To drive the train; (2) to control or effect correct combinations of the driving units to accomplish certain desired results, such as starting or accelerating a train; (3) to run at different speeds, to coast, or to reverse the direction of train movement; (4) to retard the movement of the train or to hold it on grades by application of power brakes; and (5) to generate or make steam for heating the train in cold weather.

A detailed description of the apparatus follows, but in general the equipment required to effect each of the preceding operations is as follows: Motors, motor control, master control, instruments, brakes, and oil-fired boilers.

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LOCATION OF APPARATUS

10. The apparatus within the cab is located at each side of a middle aisle that extends from end to end of the locomotive. This apparatus is grouped so that the set on each side controls the two motors mounted on one truck. With such an arrangement, all the apparatus is within view from any one position and the engineer can easily pass from end to end of the locomotive and quickly get to any part requiring his attention.

In Fig. 5 is shown each half of the locomotive cab in longitudinal section. Each piece of apparatus is in its relative position, and by the use of the indicating numbers in the list that follows the name of each piece may be ascertained.

This illustration may be more easily understood and the pictured arrangement of the equipment more clearly fixed in the mind by noting carefully the following: Imagine that a person is standing in the middle of the track and looking at the front of the locomotive. Now imagine the locomotive to be cut into two parts from top to bottom, and in direct line with the observer's eye. Then imagine that the two parts are moved bodily away from one another, and that the observer advances to a position that had been the center of the locomotive. In one of the figures a side view of the truck frames is given, while in the other figure a cross-sectional view of the motors is given. By turning to the left, the observer sees the locomotive as shown in the upper half of Fig. 5, and by turning to the right, the observer sees the locomotive as shown in the lower half. The front end of the locomotive is shown at the left in the upper figure, and at the right in the lower figure.

1, Headlight
2, Train-line receptacles, type 444D–E & F
3, Support for mounting meters
4, Forced-ventilation pipe to compressor
5, Direct-current ammeter
6, Alternating-current ammeter
7, Temperature-indicator meter
8, Equalizing reservoir
9, No. 1 master controller
10, No. 1 automatic brake valve

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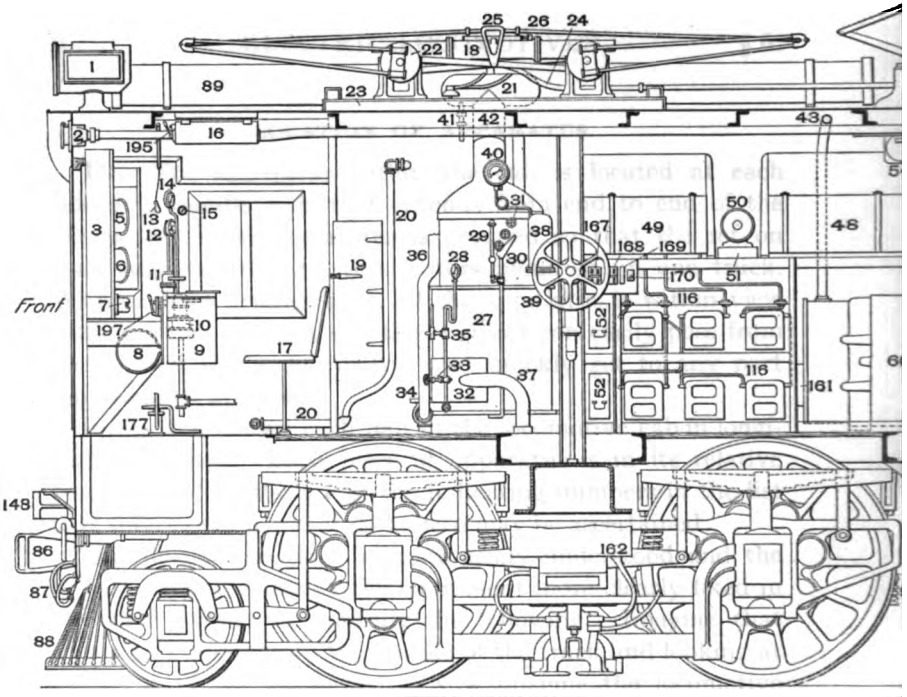

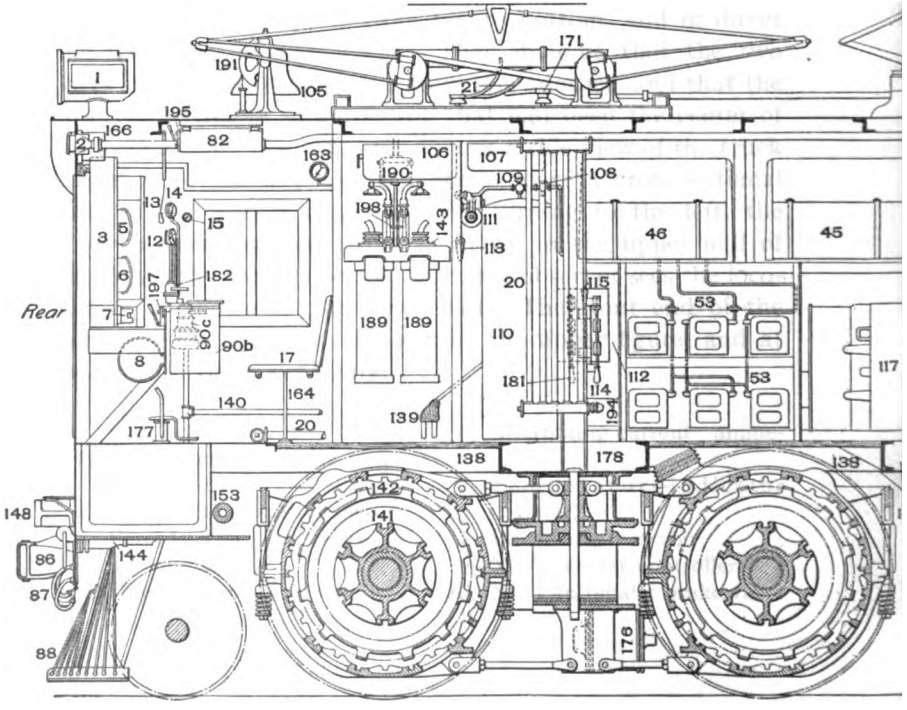

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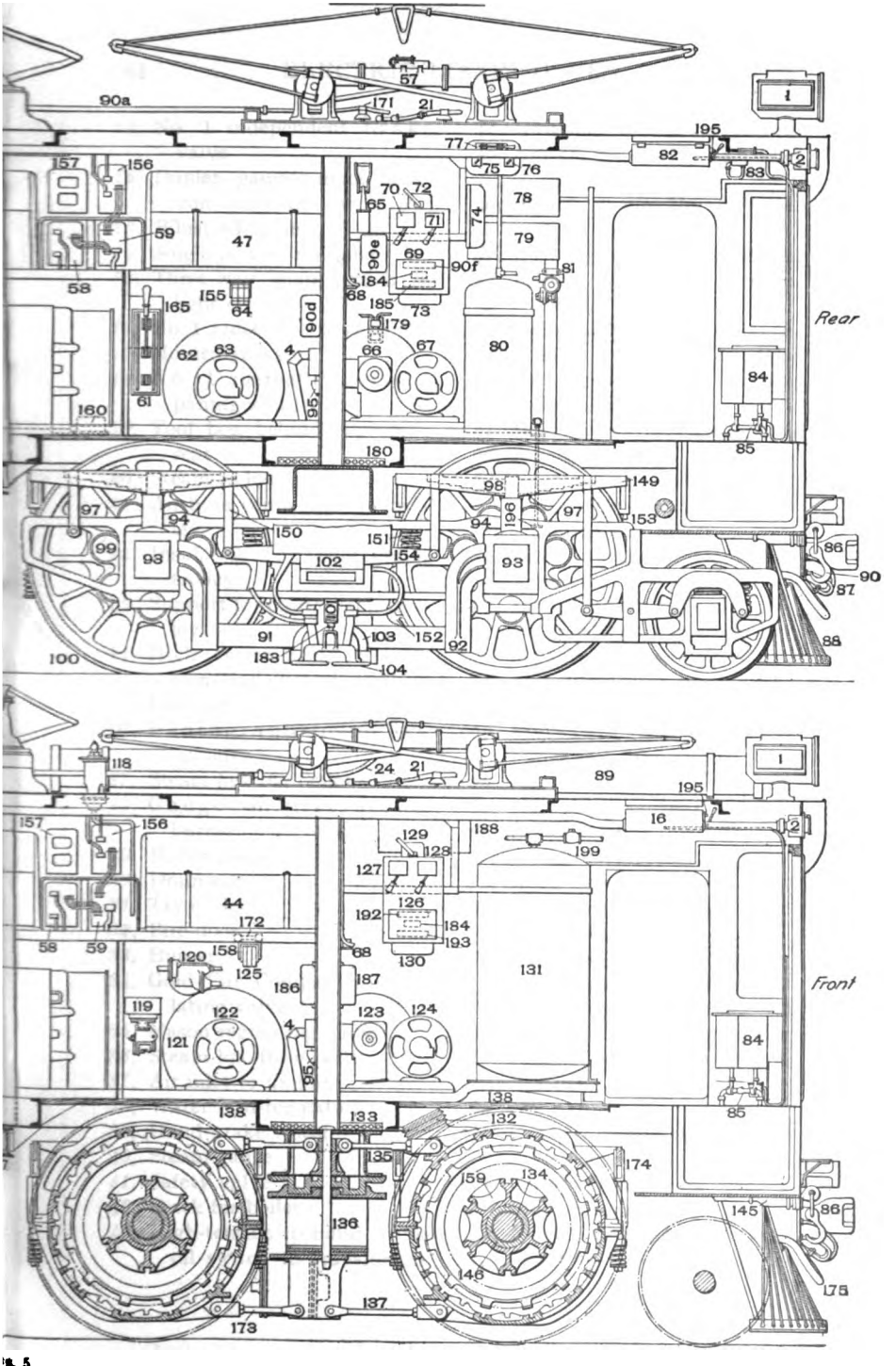

Fig. 5

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11, No. 1 independent brake valve
12, Duplex gauge—main reservoir and train line
13, Whistle handle
14, Single-pointer air gauge
15, Three-way snap switch in light circuit
16, No. 1 junction box, type 427
17, Motorman's seat
18, No. 1 alternating-current pantagraph trolley
19, Tool box behind engineer's seat
20, Steam radiators
21, Air-hose connection to trolley
22, Insulators for pantagraph trolley
23, Support for pantagraph trolley
24, High-tension cable from alternating-current trolleys
25, Pantagraph-trolley shoe
26, Pantagraph-trolley lock cylinder
27, Steam-heating boiler
28, Gauge—air pressure on burner
29, Water gauge
30, Drain cup
31, Try cocks
32, Fire-door
33, Burner
34, Gold Car Company's regulating valve
35, Mason regulating valve
36, Steam line from boiler
37, Air inlet to firebox
38, Water feed-regulator
39, Hand-brake wheel
40, Steam gauge
41, Safety valve
42, Stack for boiler
43, High-tension conduit from oil switch to transformer
44, Switch group No. 1, type 259
45, Switch group No. 2, type 251E
46, Switch group No. 3, type 257A
47, Switch group No. 4, type 259
48, Switch group No. 5, type 251E
49, Switch group No. 6, type 257B
50, Motor-generator set for battery charging
51, Base for motor-generator set
52, Storage battery
53, No. 2 set of resistance grids
54, Alternating-current integrating wattmeter
55, Base for direct-current collector
56, Direct-current collector
57, No. 2 alternating-current pantagraph trolley
58, Preventive coil—100 volts, 250 amperes
59, Preventive coil—50 volts, 500 amperes
60, No. 2 transformer
61, Main direct-current switch
62, No. 2 blower motor fan casing
63, No. 2 blower motor
64, Permanent direct-current field shunt grid
65, Hand air pump for raising alternating-current trolley
66, No. 2 air compressor
67, No. 2 air-compressor motor
68, Relay-magnet valves, type 386D
69, No. 2 fuse box
70, Canopy switch for No. 2 blower motor
71, Canopy switch for No. 2 compressor motor
72, No. 2 motor-control cut-out

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73, No. 2 alternating-current, direct-current change-over switch
74, Relay box
75, Snap switch for cab lights
76, Snap switch for headlights
77, Single-pole double-throw switch for light circuit
78, Control reservoir
79, Cover for resistance grid
80, Oil tank
81, Slide-valve reducing valve
82, No. 2 junction box, type 427
83, Signal valve
84, Sand box
85, Electropneumatic sander
86, Coupler
87, Hose couplings
88, Pilot
89, Main air reservoir
90, Hook for safety chains
90a, Cable connecting alternating-current trolleys
90b, No. 2 master controller
90c, No. 2 automatic brake valve
90d, Fuse box and fuse—alternating-current blower
90e, Battery charging relay
90f, Fuse—alternating-current compressor, No. 2 end
91, Third-rail shoe beams
92, Third-rail shoe bracket
93, Journal box
94, Truck frame
95, Suction strainer for compressor
96, Motor suspension springs
97, Spring hanger
98, Elliptical springs
99, Wheel-pocket cover
100, Main driving wheel
101, Third-rail shoe cylinder
102, Third-rail shoe fuse box
103, Main casting for third-rail shoe
104, Third-rail shoe
105, Bell
106, Alternating-current, direct-current, change-over switch, heater circuit
107, Fuse-box, heater circuit
108, Governor valve for emergency-control reservoirs
109, Three-way cock
110, Emergency-control reservoir
111, Slide-valve reducing valve
112, Balancing transformer (back of single-pole double-throw switch)
113, Combined strainer and drain cup
114, Single-pole double-throw switch, No. 1 heater circuit
115, Single-pole single-throw switch, heater circuit
116, No. 1 set resistance grids
117, No. 1 transformer
118, Whistle
119, Governor
120, Distributing valve
121, No. 1 blower-motor fan casing
122, No. 1 blower motor
123, No. 1 air compressor
124, No. 1 air-compressor motor
125, Permanent direct-current field-shunt grid
126, No. 1 fuse box
127, Canopy switch for No. 1 blower motor
128, Canopy switch for No. 1 compressor motor
129, No. 1 motor control cut-out
130, No. 1 alternating-current, direct-current change-over switch
131, Water tank
132, Air connection to motors
133, Motor leads for No. 1 and No. 2 motors

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134, Axle of main driving wheels
135, Upper torque rod
136, Center pin
137, Lower torque rod (long)
138, Trap doors over motors
139, Heater-circuit leads
140, Air-brake piping
141, Armature, No. 130 motor
142, Field frame, No. 130 motor
143, Main oil circuit-breaker
144, Bus-line socket, heater circuit, No. 2 end
145, Bus-line socket, heater circuit, No. 1 end
146, Quill
147, Tool box
148, Bumper block
149, Motor-suspension cradle
150, Spring hanger
151, Equalizer spring
152, Brake shoe
153, Steam line
154, Equalizer bar
155, Series-transformer for alternating-current ammeter, No. 3 and No. 4 motors
156, Preventive coil—100 volts, 250 amperes
157, Field shunting resistance
158, Series-transformer for alternating-current ammeter, No. 1 and No. 2 motors
159, Armature spider
160, Air inlet to transformer
161, Air inlet to resistance grids
162, Third-rail shoe leads
163, Gauge-control line pressure
164, Support for motorman's seat
165, Direct-current wattmeter
166, Blind lights
167, Double-pole double-throw switch for battery
168, Double-pole double-throw switch for battery
169, Single-pole single-throw switch for motor-generator set
170, Snap switch for motor-generator set
171, Insulators supporting alternating-current trolley cable
172, Shunt for direct-current ammeter, motors No. 1 and No. 2
173, Lower torque rod (short)
174, Motor suspension hanger
175, Steam-hose coupling
176, Brake cylinder
177, Foot push-button switches
178, Air conduit
179, Shunt for direct-current ammeter, motors No. 3 and No. 4
180, Motor leads for No. 3 and No. 4 motors
181, Single-pole double-throw switch, No. 2 heater circuit
182, No. 2 independent brake valve
183, Third-rail shoe unlock cylinder
184, Alternating-current light fuse, No. 2 end
185, Direct-current compressor fuse, No. 2 end
186, Alternating-current blower fuse and fuse box
187, Alternating-current compressor fuse and fuse box
188, Blower and compressor resistances
189, Oil tanks on circuit-breaker
190, Series-transformer
191, Hand-operated bell arrangement
192, Direct-current blower fuse
193, Direct-current compressor fuse, No. 1 end
194, Short-circuiting switch

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195, Emergency switch
196, Emergency oil valve
197, Trolley and third-rail-shoe safety switch
198, Overload trip (main circuit-breaker)
199, Water-tank check-valve

MOTORS

11. Frame.—The motors are of the single-phase type, and each is capable of developing 250 horsepower for 1 hour, and 200 horsepower continuously. The motors are also gearless; that is, the armatures drive the wheels direct and not through trains of gears, as is usually the case.

A complete motor mounted on an axle and a pair of wheels is shown in Fig. 6. The opening through which air is forced

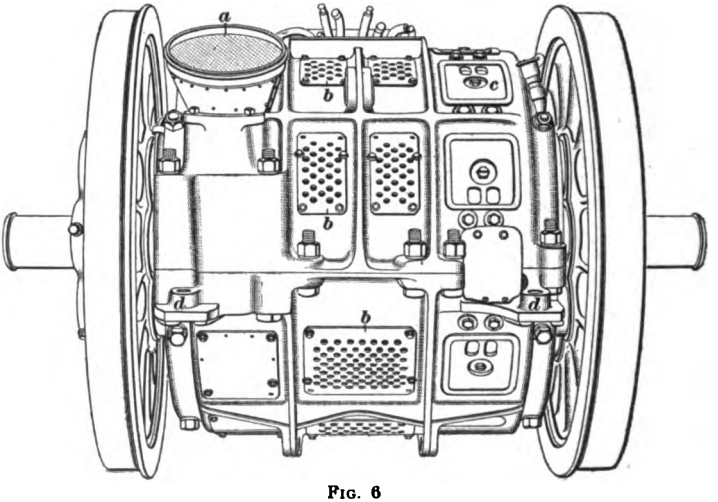

FIG. 6

to cool the motor is shown at *a*. This opening is fitted with a cover of wire gauze in order to prevent foreign material from getting into the interior of the motor. At *b* are shown the openings through which the air is discharged into the atmosphere after it has circulated through the motor and has absorbed most of the heat generated by the motor. By the use of forced ventilation the motor may be worked harder with the same temperature of the windings.

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One handhole cover is provided at each of the brush holders, as shown at *c*. The covers are released by fitting a box wrench on the bolt head in the central recess and giving it a quarter turn, when the cover may be removed easily. At *d* are shown the supporting bosses, or lugs, having holes drilled through them and to which the frame supporting rods are connected. These rods are attached to the motor cradle, or yoke, indicated in Fig. 3. By adjusting these rods, that portion of the motor weight transmitted to the axle boxes through the saddle may be adjusted. The motor frame, Fig. 6, is kept from turning on the axle by torque rods, one at the top and two at the bottom, and these rods are connected to the transom of the truck bolster.

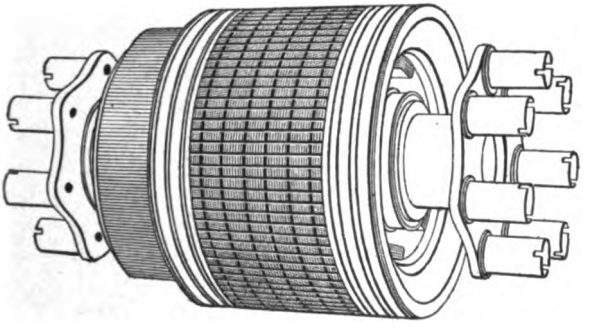

FIG. 7

12. Armature.—The armature is built on a hollow shaft, or quill, having flanged ends. The quill fits loosely over the axle, with a clearance of approximately $\frac{1}{8}$ inch. In Fig. 7 is illustrated an armature and quill.

As shown, each flange is fitted with seven hollow pins. These pins fit into corresponding pockets, Fig. 8, called *spring pockets*, in the cast-steel centers of the wheels. Each pin fits within an eccentrically wound spring that modifies the effects of all blows and sudden shocks. The springs are kept in place by a cap that screws into the spring pocket. An armature and a pair of wheels are shown in Fig. 8.

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13. General Description.—In general respects, the motors are similar to the usual types of direct-current railway motors of equal capacity. The iron of the poles and yokes, as well as of the armature core, is, however, laminated in this type of motor. A set of neutralizing coils is placed in slots provided in the faces of the poles.

Each motor has twelve poles. Each alternate pole is fitted with a main-field coil, the other poles being consequent poles. All the pole faces are slotted and fitted with neutralizing coils, and all the field coils are connected permanently

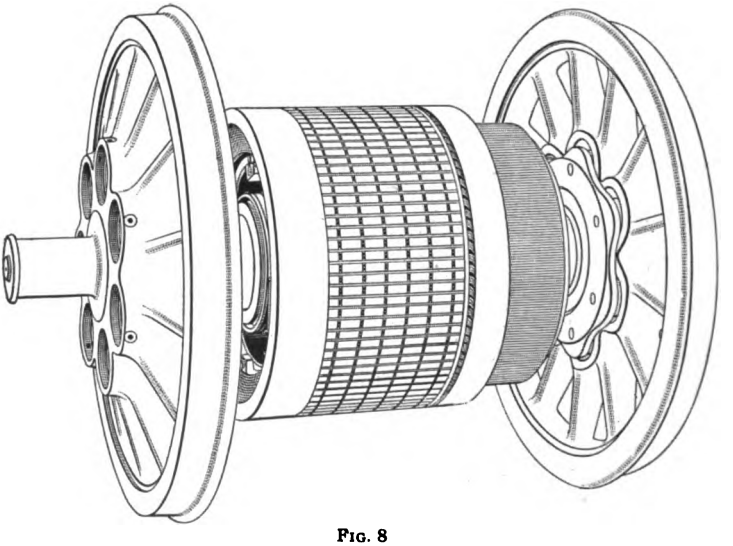

FIG. 8

in series. The final two leads or connections extend through the case and are connected to certain of the unit switches. The neutralizing windings are connected permanently in series with each other and with the armature.

There are twelve brush holders, each one of which is fitted with three carbon brushes that are electrically connected to the brush holders by means of flexible copper shunts. The brush holders are insulated from, but securely fastened to, the motor frame, and are adjustable. Brush holders of like polarity are connected in parallel through copper rings,

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insulated from, but rigidly attached to, the end of the motor frame. Leads from the rings extend through the motor case and are connected to certain of the unit switches.

When operating in the alternating-current zone, each group of motors has a maximum potential of 550 volts across the terminals. The method of grouping the motors will be explained later.

If operating in the direct-current zone, the maximum line voltage, which is 650 volts, may be impressed across the outside terminals of the group of four motors when operating in series, or across the outside terminals of each pair of motors, when operating in parallel.

MOTOR-CONTROL APPARATUS

14. Circuit-Breakers.—The circuit-breaker, or line switch, used when operating with direct current is one of the unit switches of the switch groups to be described later. There are two circuit-breakers used when operating with alternating current—one for each transformer. These circuit breakers have the main contacts immersed in oil contained in an enclosed tank.

When it is desired to close a circuit-breaker, it may be done in one of two ways: (1) By pressing on the master controller a button that causes a magnet to open an air valve, allowing compressed air to move a piston attached to the moving arm of the circuit-breaker, or (2) by forcing down the handle shown at *a*, Fig. 9.

Should the current taken from the trolley by the circuit-breaker exceed an amount for which the circuit-breaker has been set, a magnet in the relay, box *b*, Fig. 9, will operate a trip and cause the switch to open. The breaker will then remain open until reset. The circuit-breaker may also be opened by hand.

15. Transformers.—There are two autotransformers, one for each pair of motors. These devices reduce the voltage from 11,000 at the trolley to that required for the motors.

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The action of an autotransformer is explained in *Single-Phase Speed Control.*

Fig. 10 shows a transformer and also indicates the manner in which the high-tension leads *a* and the low-tension leads *b* are brought through the transformer case. The inspection cover at one end is removed so as to show the coils. The transformers are of the *air-blast type;* that is, they are cooled

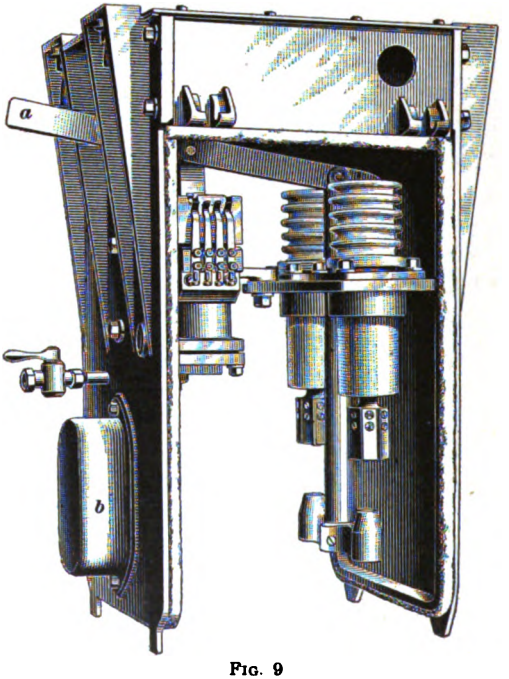

FIG. 9

by a blast of air in the same manner and from the same source as the motors. The air enters one end of the transformer at the bottom of the case, and, after passing through air paths in the coils and iron core, it passes into the atmosphere through an opening in the side at the opposite end of the case.

16. Switch Groups.—As indicated in Fig. 5, there are six separate switch groups, three on each side of the loco-

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motive. These switches have three distinct sets of operations to perform, as follows:

1. They are arranged so that closing certain switches, by manipulating the master controller handles, will connect the armature and field coils of each motor for train movement in a desired direction. If it is desired to reverse the direction of train movement, other switches in the same group may be made to reconnect the armature and field for reversed

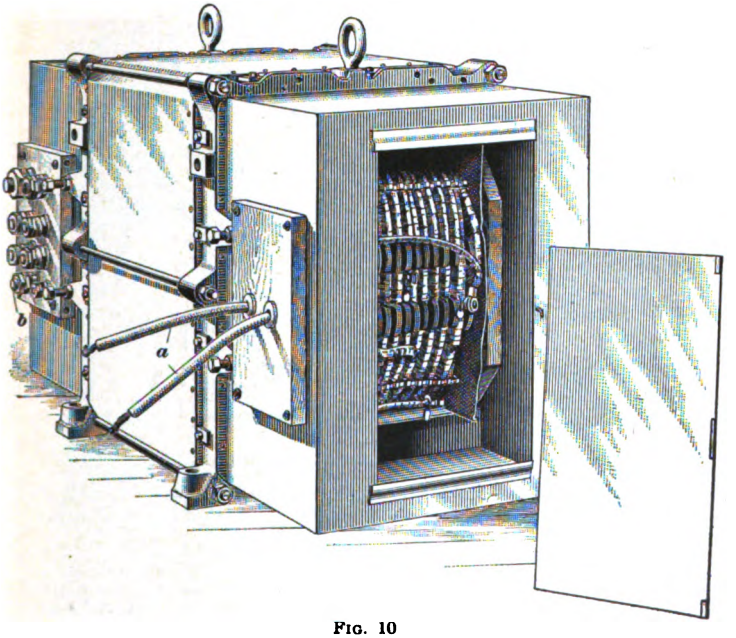

FIG. 10

direction of armature rotation. These switches perform the same duty for both direct-current and alternating-current operation.

2. When operating with direct current, certain switches connect the four motors into two groups, each group consisting of two motors in series. Each of the two pair of motors thus formed is controlled as a single unit. Other switches first connect the two pair, or the four motors, in series with a resistance for slow running, the resistance being

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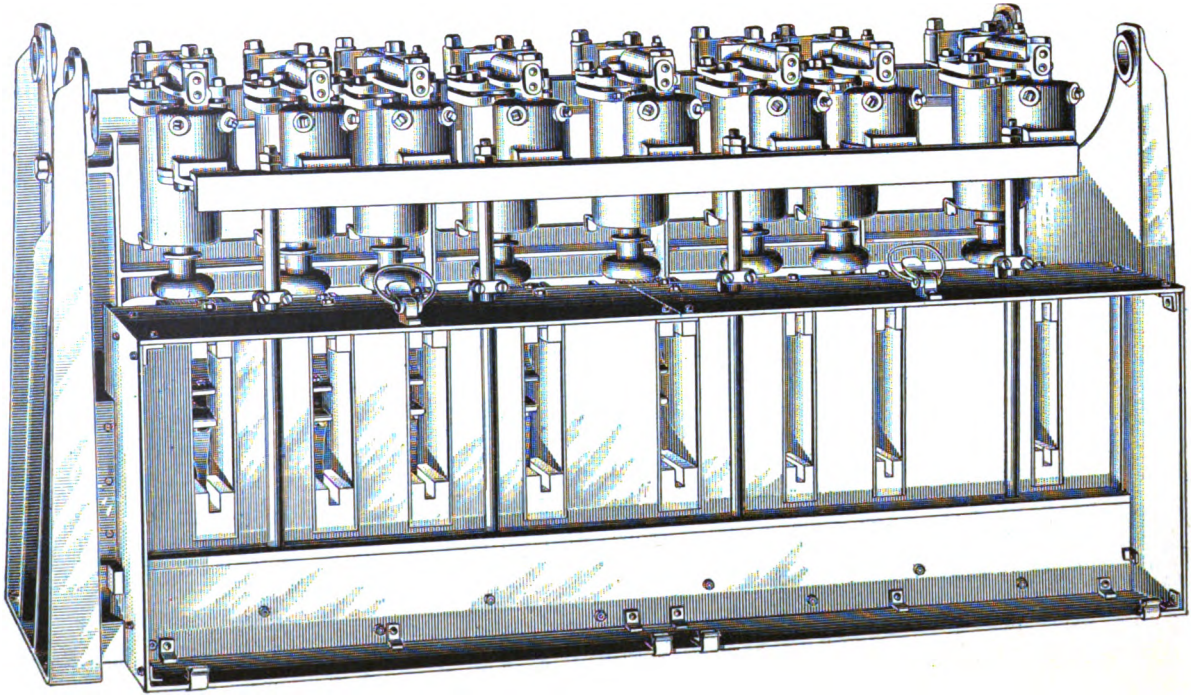

FIG. 11

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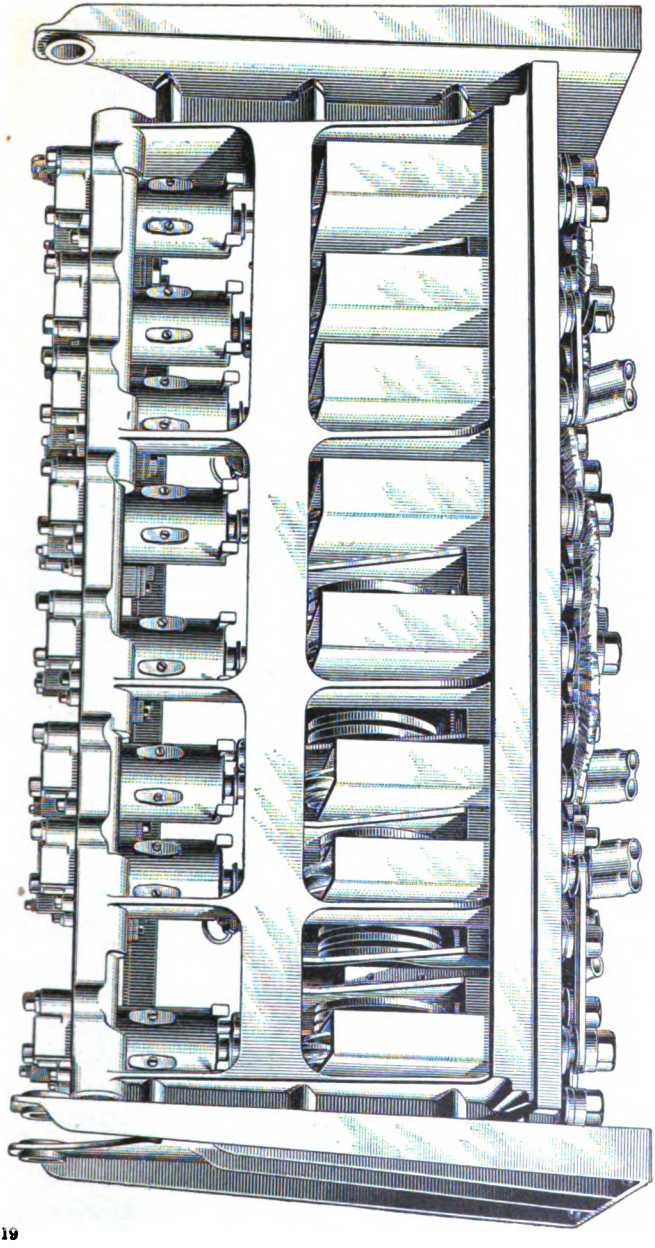

Fig. 12

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gradually cut out of circuit during starting. Next, other switches connect a resistance in shunt with the motor fields for higher speed. For still higher speed, and the highest attainable speed, other switches connect the two pair of motors in parallel.

3. For alternating-current operation, the four field coils of the motors are connected permanently in parallel by switches of the same switch group as is used in direct-current operation to connect the motors in series and series-parallel. The two armatures of a pair of motors are connected in series, and the two pair of armatures are connected in parallel.

Switches not used for any of the operations just mentioned are now used to connect the motors progressively to various

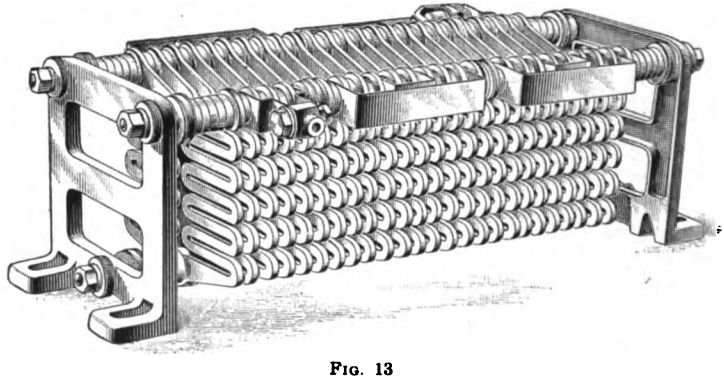

FIG. 13

taps on the transformers, each tap giving a higher voltage than the preceding one, so that the speed of the motors increases as the taps are connected.

In Fig. 11 is illustrated a group of direct-current switches, showing the front of the containing case with the covers removed, and in Fig. 12 is shown the same group of switches as it appears from the back. The alternating-current switch groups are the same as the direct-current switch groups, but they are somewhat smaller in size.

17. Preventive Coils.—There are six preventive coils, three for each transformer and its switch groups. These

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coils are illustrated and their action explained in *Single-Phase Speed Control.*

18. Rheostats.—When operating with direct current, resistance is connected in circuit with the motors while accelerating the train. The current passing through the motors is kept nearly constant, and, therefore, the tractive, or turning, effort developed by the motors is kept nearly constant by gradually cutting this resistance out of circuit until full-line voltage is applied across two motors connected in series.

A frame of resistance made up of alloy grids is shown in Fig. 13. There are twelve such frames in this locomotive, six frames being arranged on each side, as indicated in Fig. 5. The resistance is enclosed in sheet-iron casing, and it is cooled by a blast of air from the same source as that used by the air-cooled transformers, the air first passing through the transformers. This arrangement is suitable for the operating conditions, because the transformers are used alone when operating with alternating current, and the resistance is used alone when operating with direct current.

19. Main Direct-Current Switch.—The main direct-current switch *61*, Fig. 5, is a large single-pole, double-throw knife switch. This switch is arranged so that the motors may be operated with direct current from the collector shoes when the switch is in its lower position, and the motors may be operated with alternating current from the collector rail when the switch is in its upper position.

Alternating current at low voltage is used on the third rail at the Cos Cob drawbridge only in case a train should come to a stop there for any reason. Ordinarily, a train coasts over this bridge, as it cannot be equipped with trolley, though it is in the alternating-current zone. In case this short section of third rail is used, the current in the motors is regulated by resistance the same as for direct-current operation.

20. Third-Rail Shoes.—As indicated in Fig. 1, the third-rail shoes are fitted to each side of each main truck. In this figure, the collector shoes are shown raised so that they

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will not strike obstacles along the road when the locomotive is operating in the alternating-current zone.

The shoes are raised and lowered by compressed-air cylinders. By pressing a button on the master controller, a magnet is energized that opens a valve and lets air into the cylinder. This air causes the piston to move downwards, thus lowering the shoes so that they will engage the third rail. When it is desired to raise the shoes, another button on the master controller is pushed. This operation energizes a magnet that opens a valve and lets air into a small cylinder, the piston of which moves forwards rapidly and strikes a toggle-joint, relieving the shoes, which are then raised by a spring located behind the piston in the main cylinder.

The overhead shoe near the middle of the roof of the locomotive, Fig. 1, is for use in the direct-current zone, where, owing to cross-overs, long gaps occur in the third rail. This collector is used chiefly in the yards at Grand Central Station. The shoe is raised by pressing a button at the master controller; it remains up as long as the button is being pressed, but drops instantly when the button is released.

21. Pantagraph Trolleys.—There are two pantagraph trolleys on top of the locomotive. These are used to collect the current when operating in the alternating-current zone. One of them is shown in its raised position and in contact with the trolley wire in Fig. 1. To lower these trolleys, a button on the master controller is pushed. This operation energizes a magnet that moves a valve, thus allowing air to enter the operating cylinder of the trolley and to press against pistons that lower the trolley. A catch engages and holds the trolley in this position.

When it is desired to raise the trolley, it may be done in one of three ways: Thus, if there is no compressed air on the locomotive, a condition that may obtain after the locomotive has been standing idle for some time, (1) a hand pump, as shown at *65*, Fig. 5, may be used; (2) a three-way cock, as shown at *109*, Fig. 5, may be turned to the right; or (3) a button on the master controller may be pressed.

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Each of these methods results in air entering a cylinder and forcing a piston to one side. An extension on the piston unlatches the trolley, which, in turn, is raised by springs back of the main pistons.

22. Shoe Fuse.—Each collector shoe is fitted with a fuse placed in a box that is installed immediately over its respective shoe and supported from the underframing of the cab, as indicated in Fig. 1. These fuses are made of copper strip and are of such size that they will melt if the wiring

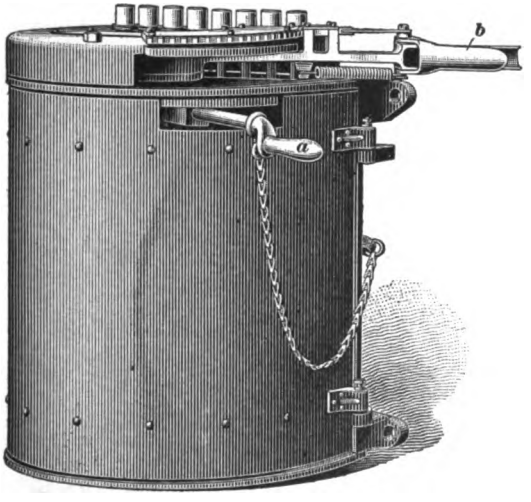

FIG. 14

between them and the switch groups becomes grounded or short-circuited.

23. Blowers.—The blowers are of the ordinary type and are driven by electric motors. They furnish a large volume of air at low velocity and at a pressure of approximately 6 ounces per square inch, for cooling the motors, transformers, and resistances.

In Fig. 5, the blowers are shown at *62* and *121*, and the motors at *63* and *122*.

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24. Master Controllers.—There are two master controllers, one at each end of the locomotive. A master controller, which is of the small drum type, is shown in Fig. 14. It has two drums, the reverse drum being operated by the handle *a*, and the main drum, by the ratchet handle *b*.

In Fig. 15 is shown the top of the master controller, as well as the positions of the handles for the various conditions of

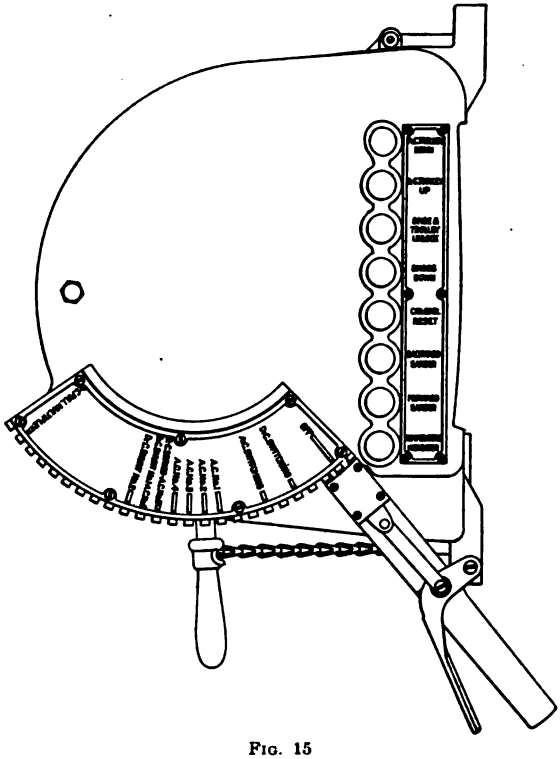

FIG. 15

running. The same handles are used for both direct- and alternating-current operation. The push buttons and the purpose of each are also indicated in the figure.

In Fig. 14, a small plug is shown connected by a chain to the reverse handle. When inserted in the receptacle, this plug completes the connection between the master controller

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and a storage battery. The handle for operating the main drum is permanently attached, but the reverse handle can be removed only when in the off-position, shown in Fig. 15. These two handles are interlocked by mechanical means, so that the main drum cannot be rotated unless the reverse handle is set at either *forward* or *backward* position. The

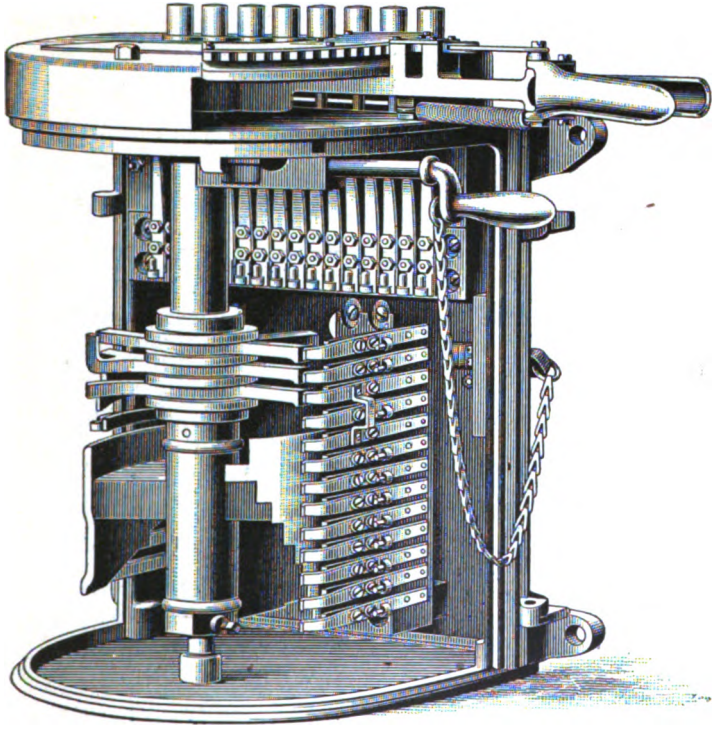

FIG. 16

lettering in Fig. 15 indicates the result of each movement of the handles or of the push buttons.

In Fig. 16 is shown a master controller of the general type used on these locomotives. The general arrangement of push-button switches, reverse fingers, and main-drum fingers is also indicated.

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25. Relays.—An interesting part of the equipment is the arrangement of relays. These devices automatically change the connections of the apparatus so that it may operate with alternating current after leaving the direct-current zone or with direct current after leaving the alternating-current zone.

These relays are shown in Fig. 17. The relay at the left is for direct current, one only being required, as all third-rail shoes are connected in parallel. The two relays at the right are for alternating current. These two relays, one for each pantagraph trolley, are necessary, because the trolleys may be operated singly or together.

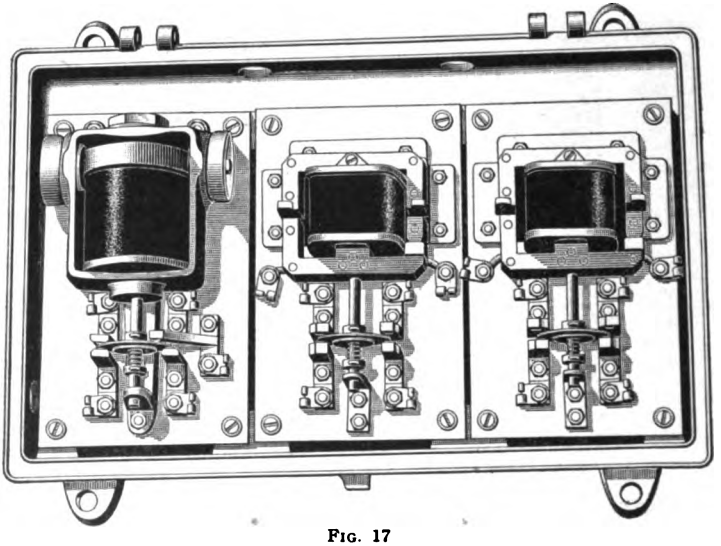

FIG. 17

To make clear this action, assume that a locomotive is running with direct current and is approaching the alternating-current zone. The motorman throws the master controller to the off-position, presses the button marked *shoe and trolley unlock*, and holds down this button until the shoes leave the third rail, when the shoes will fold up to the side of the locomotive and the pantagraph trolleys will raise. When the trolleys touch the wire, the alternating-current relays are energized. They then lift their disks, which now bridge the

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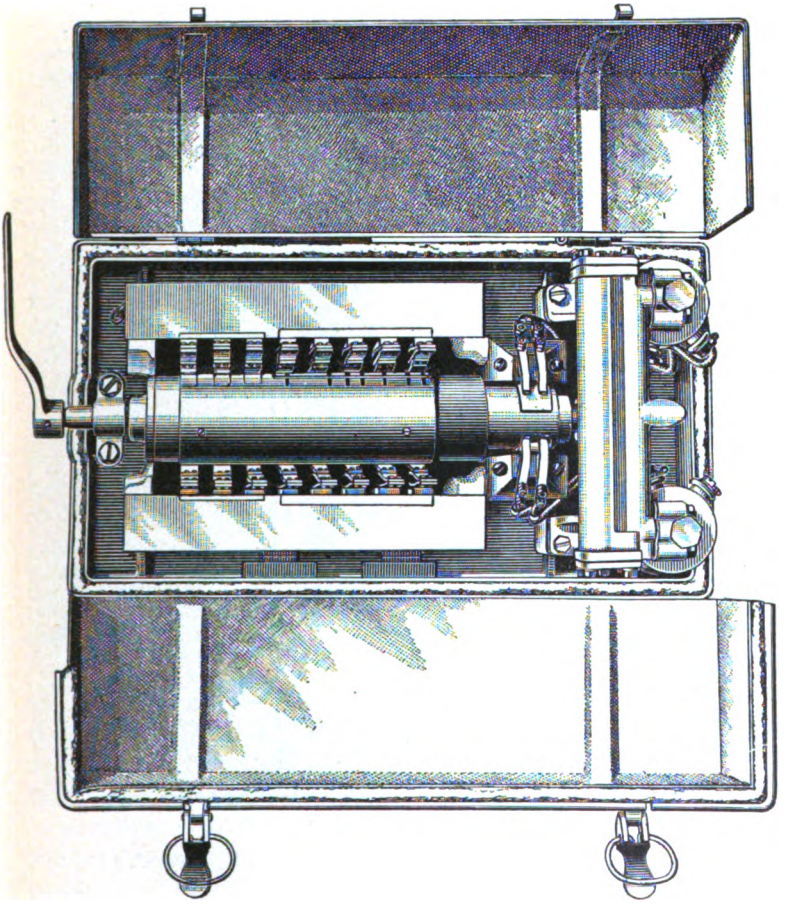

Fig. 18

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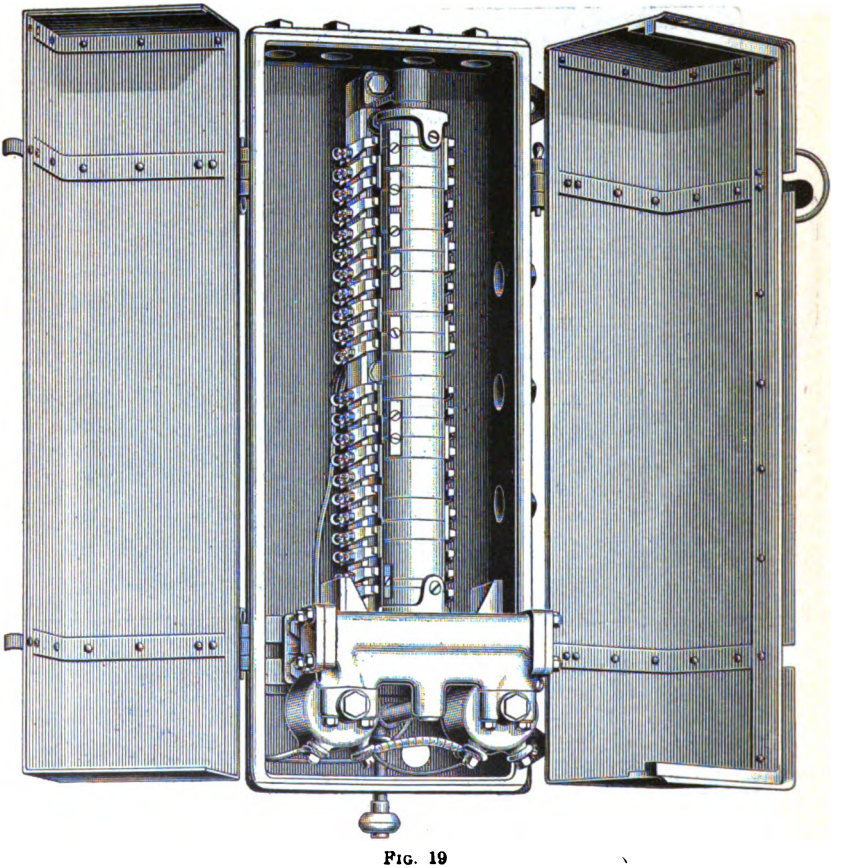

FIG. 19

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upper contacts, thus establishing circuits that cause the two change-over switches to be rotated. One of these switches changes the heater circuits, and the other, the master-control circuits.

26. Change-Over Switches.—The heater change-over switch is shown in Fig. 18. This switch may also be operated by hand by means of the lever. The drum of this switch has an extended shaft that is fitted with a pinion. This pinion engages a rack, and each end of the rack is fitted with a piston that moves within an air cylinder. The rack is moved forwards or backwards, according to which cylinder is filled with compressed air. The air is controlled by valves actuated by magnets energized by the relays. The shaft and drum is thus rotated in one direction or the other by the movements of the rack.

In Fig. 19 is shown a type of change-over switch for the master-control circuits. The action of this switch is the same as for the heater change-over switch. The purpose of the master-control change-over switch is to arrange the master-control circuits so that the proper switches may be closed for either alternating- or direct-current operation.

27. Motor-Control Cut-Out.—Each locomotive is equipped with two motor-control cut-outs, one for each pair of motors. They are operated by hand. By placing the switch handle in one position, the master-control circuits are made operative, and the motors may be supplied with power in the usual manner. By placing the switch handle in a second position, certain master-control circuits are made inoperative, so that the power switches for the corresponding motors remain open. These motors, therefore, cannot receive power.

28. Train-Line Cable.—The train-line cable comprises the cable and connectors used to join the master-control circuits of two or more locomotives coupled together and to be operated from the master controller of the forward locomotive. The cable is of the ordinary multicore type.

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The connector sockets are six in number, three at each end of the locomotive. They are located under the headlight and are protected by the canopy. The socket is fitted with a spring-closed cover, which prevents the electrical parts from becoming wet. The sockets at the adjacent ends of two locomotives are connected by means of jumpers of the type shown in Fig. 20. Each jumper has two heads, with brass recesses that fit on corresponding brass pins in the sockets. The recesses of the heads are connected by means of copper wire.

29. Storage Battery.—A storage battery is used to supply power to the master-control circuits when the valve

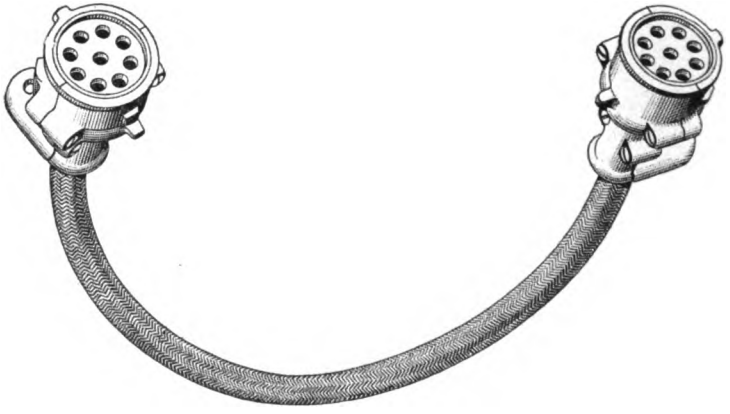

FIG. 20

magnets are being operated. The battery consists of two sets of cells. One of the sets is charged while the other is in use. When operating in the alternating-current zone, the batteries are charged from a small motor-generator set that is driven by an alternating-current motor. The generator supplies direct current at about 20 volts. When operating in the direct-current zone, this set is cut out of circuit by means of a switch operated by the motorman. The battery, when operating in the direct-current zone, is charged through a relay and resistance.

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30. Instruments.—At each end of the locomotive, and in front, but to the left, of the motorman's seat, as shown in

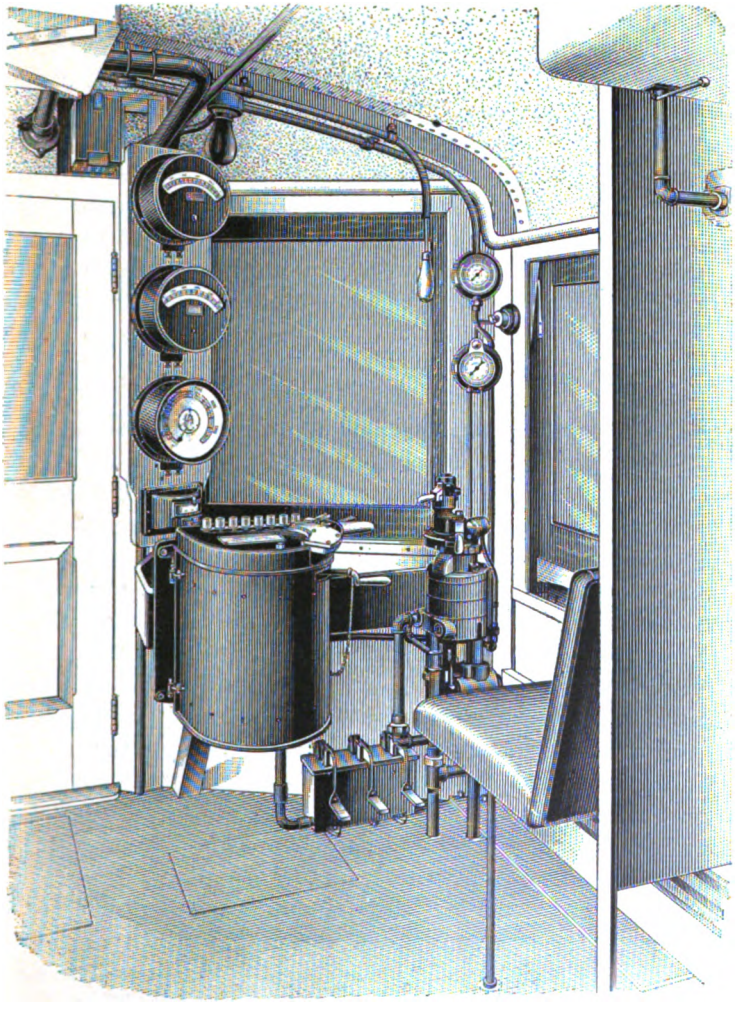

FIG. 21

Fig. 21, are four instruments. Starting at the top, these instruments are as follows: A speed indicator, which is so

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arranged as to indicate the speed of the locomotive in miles per hour; a direct-current ammeter, which indicates the current taken by each motor when operating in the direct-current zone; an alternating-current ammeter, which indicates the current taken by each motor when operating in the alternating-current zone; and a temperature indicator, which shows the temperature of the motors when a button on the master controller controlling the indicator is pressed.

In addition to the instruments just named, there is a direct-current and an alternating-current wattmeter located near the middle of the locomotive. One or the other of these instruments permanently records the energy used by the locomotive when operating in the direct- or the alternating-current zone.

ELECTRIC CIRCUITS

31. In Fig 22 is shown a complete wiring diagram for the type of locomotive under consideration. The portions of the control circuits that are active on the tenth step, which is the first running position on direct-current operation when all motors are in series, are indicated in blue. The other portions of the control circuits are indicated in red. The portions of the motor circuits that are active on the first running position are indicated in green, and the other portions of the motor circuits are indicated in black. Circuits for the auxiliary apparatus are also shown in black. To simplify the diagram, master-control wires that lie in the same direction are shown grouped in a multicore cable, but no confusion will arise when tracing a circuit if is is borne in mind that each circuit is indicated by a number and the circuit wires can always be distinguished in that way.

In some instances, a branch circuit is distinguished by a number differing from that of the main circuit. In such cases, the main circuit should be traced to its conclusion, and this circuit should be firmly fixed in the mind before attempting to trace the branch circuit.

In the junction box, terminals having the same number are connected together, and they are to be so considered when

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tracing a circuit, though they are not so shown in the diagram. A schematic arrangement of the electric apparatus and a table of the sequence of the closing of the switches for both direct- and alternating-current operation are also shown in Fig. 22.

BRAKES

32. The air-brake equipment comprises the parts inside of the cab and also those underneath the cab, but the inside parts are the ones of interest in this Section and will therefore be described.

33. Air Compressor.—There are two duplicate air compressors, one of which is shown in Fig. 23. This com-

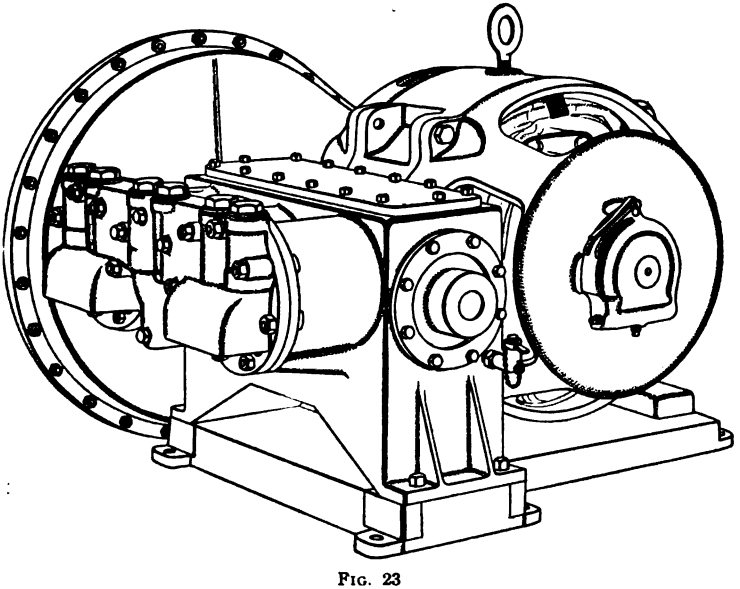

FIG. 23

pressor has two pistons connected to a crank that is driven through gears by a motor and that dips into an oil bath. The cylinder heads, which also form the valve housings, are cooled by an air blast. The motor is designed to operate with either alternating or direct current.

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Each air compressor is provided with an automatic governor, the pnuematic part of which is connected to the air

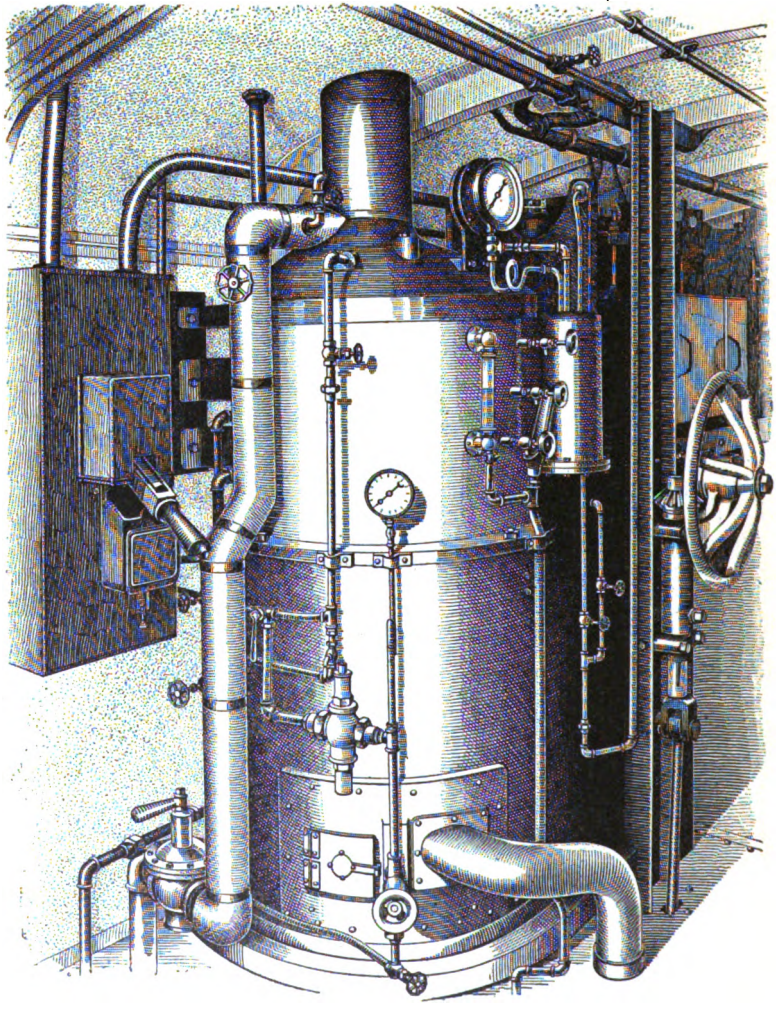

FIG. 24

reservoir and the electric part, to the motor circuit. The action of the governor is as follows: When the air in the

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reservoir reaches a certain low pressure, the governor closes a switch, and this causes the motor to start. The motor continues to run until a certain high pressure is reached, when the switch is opened automatically and the motor stopped.

34. Engineer's Brake Valve.—The engineer's brake valve is of the E. T. type and has two operating handles, one to operate the brakes throughout the train and the other to operate the brakes on the locomotive only. The latter handle is used to steady the train or to hold it in a station or on a slight grade, so that little time will be lost in making a start. A brake valve is fitted at each end of the cab.

There are two air-pressure gauges in front of the motorman's seat. The upper gauge has one hand, which indicates the pressure in the brake cylinder when the brake on the locomotive only is used, and the lower one has two hands, one of which indicates reservoir pressure and the other train-line pressure. The brake valve and gauges are shown in Fig. 21.

HEATERS

35. Description of Heater Apparatus.—Provision has been made to heat the trains by either electricity or steam. The electric heaters are of the customary type.

For heating the train by steam, each locomotive is equipped with a steam boiler, as shown in Fig. 24. The boiler is fired with oil, which is stored in a tank at one end of the locomotive and is forced into the furnace by compressed air. The feedwater is stored in a tank on the opposite side of the locomotive from the boiler, and is forced into the automatic feedwater regulator by air pressure.

The pressure of the steam in the train line is regulated by a hand-operated valve, and is adjusted according to the number of cars in the train. Two steam gauges are provided, one to indicate the steam pressure in the train line, and the other to indicate the steam pressure in the boiler. The safety valve in the boiler is set to blow off at 80 pounds, and a pressure of at least 75 pounds should be carried.

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A regulating valve, shown near the lower left-hand portion of Fig. 24, is provided for cutting the steam pressure down in the train line, and a gauge is provided for showing the pressure on the train line. This gauge should register a pressure of 5 pounds for each car in the train that is being heated.

The oil supply for firing the boiler reaches the boiler at a pressure of about 25 pounds. This supply is regulated by a

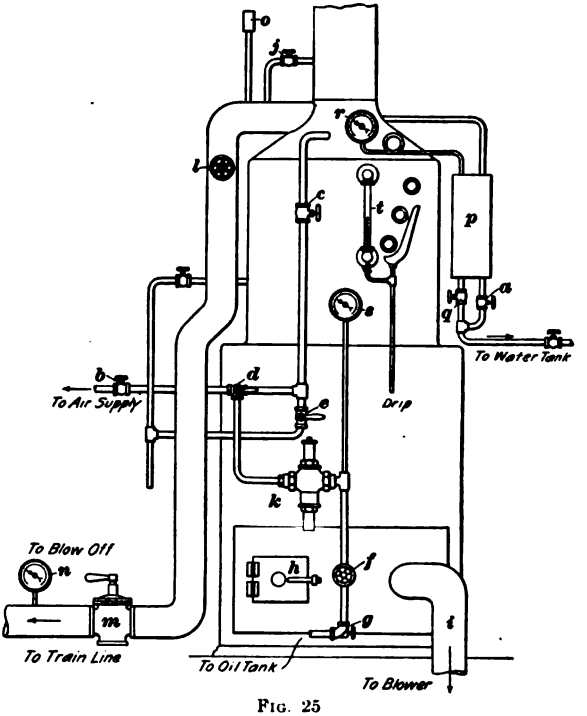

FIG. 25

globe valve, which is a part of the burner. In the burner, the oil is broken up and forced into the firebox by a blast of steam from the boiler.

36. Operation of Boiler.—The method of operating the boiler is as follows:

1. To start the boiler, fill it with water so that about 1½ inches shows in the water gauge. This can be done by

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opening the by-pass valve *a*, Fig. 25, and allowing the water to flow until it reaches the required level.

2. See that valves *b*, *c*, *d*, *e*, and *f* are closed. Open valve *g* in the oil line and then momentarily open valve *f* and see that oil flows freely from the burner. The burner can be observed through the small door *h* in the firebox.

3. Close valve *g* in the oil line; open valve *b* in the air line and throw the handle of the three-way valve *d* to down position; then momentarily open burner valve *f* and see that air flows freely through the burner.

Saturate a piece of waste with oil; light the waste and throw it into the firebox through door *h*. Open valve *g* to the oil line and open burner valve *f*. As soon as the oil ignites, adjust the flame to the desired height by means of valve *f*. Start the blowers on the locomotive (if not already running), and open damper *i* in the draft supply about half way. As soon as steam pressure begins to show up, open the jet valve *j* near the stack.

5. When a steam pressure of 75 pounds has been reached, the burner should be thrown from the air to the steam line. In order to make this change, close valves *f*, *g*, *b*, and open valve *c* in the steam line to the burner; then open valve *e* to the drain pipe and let steam blow through for a few minutes to heat the pipe and get rid of condensation. Next, close valve *e*, throw the handle of the three-way valve *d* to its extreme right-hand position, open burner valve *f*, and allow steam to blow through the burner until regulating valve *k* and the pipe connecting to the burner are heated; then close the valve. Open valve *g* in the oil line, throw a piece of burning waste into the firebox, open valve *f*, and adjust the flame to the desired point, as before.

6. When the boiler is steaming satisfactorily, open valve *l* and by means of valve *m* adjust the pressure on the steam train line according to the number of cars that are to be heated. The pressure in the steam line can be read on gauge *n*, and it will be found that a pressure of about 5 pounds per car will be required under ordinary conditions. The steam pressure may be adjusted to suit different atmospheric conditions.

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The regulation of the burner valve *f* and the jet valve *j* will have to be varied according to the load that is being carried. A little experience will enable the operator to judge the necessary regulation for different loads.

The safety valve *o* is set to blow at 80 pounds. If this valve blows frequently, it shows that more fire is being carried than is necessary.

The level of the water in the boiler is regulated automatically by means of the regulator *p*, valve *q* being open. The by-pass valve *a* should always be kept closed under ordinary operating conditions. If the water regulator fails to act and the water level drops, the by-pass *a* can be used to regulate the level by hand.

The gauge that indicates the pressure of the steam in the boiler is shown at *r*, the gauge that indicates the air pressure on the burner at *s*, and the water gauge at *t*.

GRAND TRUNK RAILWAY—ST. CLAIR TUNNEL LOCOMOTIVE

SERVICE CONDITIONS

37. The Grand Trunk Railway Company experienced a great deal of trouble with smoke and gases in the St. Clair tunnel, and in order to overcome this difficulty and to increase ultimately the number of trains passing through the tunnel, the railroad officials decided to electrify the tunnel and the adjoining yards. The trains run on this road are very heavy, and the grade is 2 per cent. Therefore, in order to perform its duty, a locomotive must have great hauling capacity, or a large draw-bar pull, at the low speed of approximately 15 miles per hour.

After an exhaustive study of the conditions of service it was decided to equip this section of the road with single-phase, alternating-current power. One locomotive is used to haul the lighter trains, and two locomotives, operating double-

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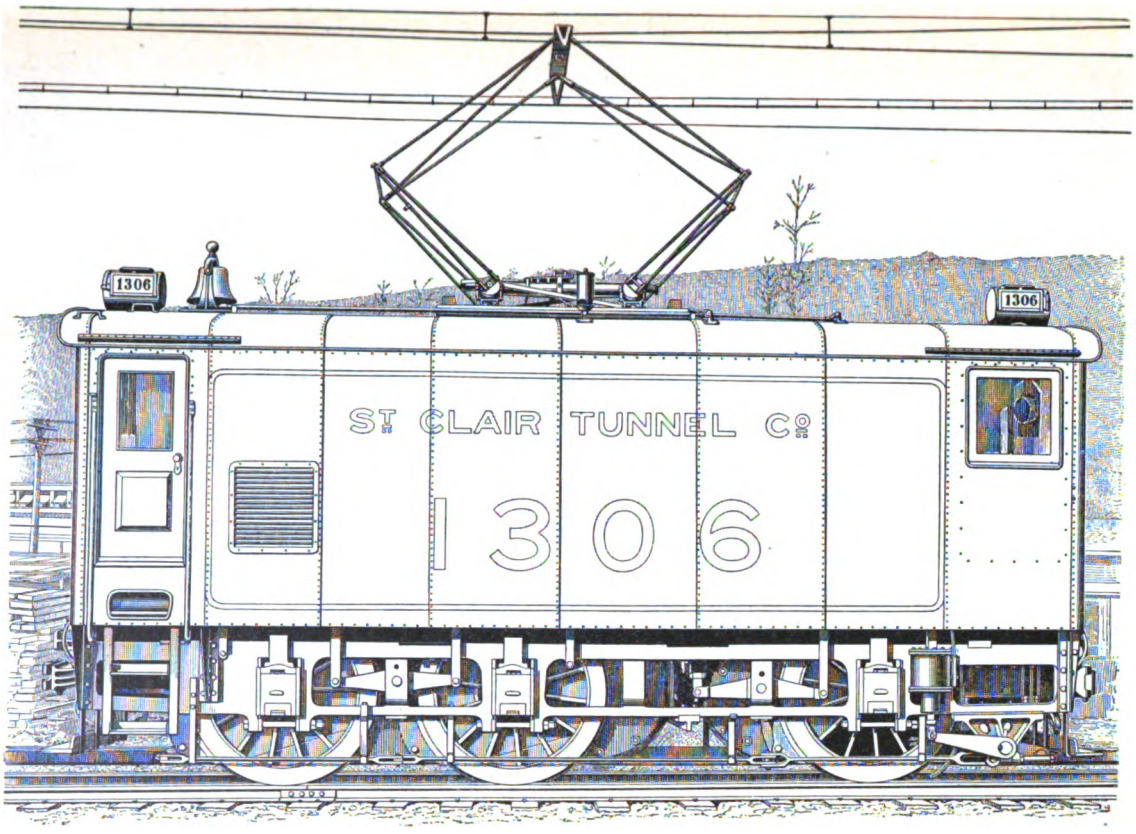

FIG. 26

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header and both controlled by the motorman on the leading one, are used to haul the heaviest trains.

The power house is situated at the Port Huron end of the tunnel, and is equipped with steam turbines that drive alternating-current generators. These generators supply single-phase power direct to the trolley system at 3,000 alternations per minute (frequency 25 cycles) and at a pressure of 3,300 volts between the trolley wire and the track rails.

GENERAL DESCRIPTION OF LOCOMOTIVE

38. A completely equipped locomotive, such as is used on the Grand Trunk Railway, is illustrated in Fig. 26. It comprises three principal parts, namely, the cab, the truck, and the equipment.

39. Cab.—The cab is composed of a strong skeleton of **Z** bars and angle irons. These are bent to shape and are securely fastened together with gusset plates and rivets. This skeleton is covered with sheet-steel plates riveted to the **Z** bars, and the inside of the cab is covered with a cork-cement lining so as to keep out the cold during winter.

On each side and at opposite ends of the cab are a door and a window. The door is to provide access for motormen and inspectors, while the window, which is of the drop type, is for the use of the motorman, in case the windows at the front become coated with snow or ice.

At each end are two windows and a door. The doors are in the middle of the end sections and are used in passing from one locomotive to another in double-header operation. All doors open inwards, so that they cannot fly open and strike objects near the track.

On each side of the cab near the end are ventilating panels. One ventilating panel is to provide cool air at the blower intake, and the second is arranged for discharging into the atmosphere the air that has been forced through the transformer.

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40. Under Frame.—The under frame is composed of side and center channels arranged lengthwise of the locomotive. These channels are secured by cross-sills, and the cross-sills are connected by gusset plates and knee braces that are firmly fastened by means of rivets. The end frames are composed of heavy channels reinforced with knee braces. The whole frame is designed to withstand heavy strains most effectively.

41. Couplers and Draft Gears.—The car couplers are of the automatic type, and are equipped with the

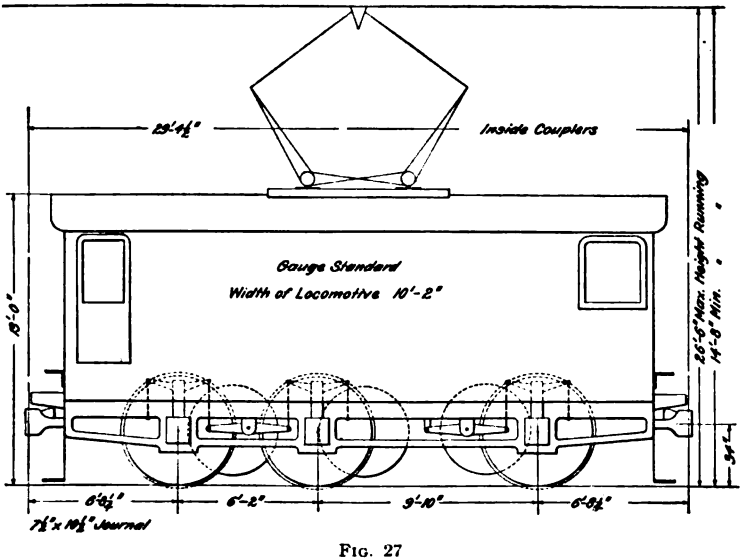

FIG. 27

Westinghouse friction draft gear. The couplers and draft gear are fitted to the end frames of the truck.

42. Trucks.—There is one continuous truck, with three axles. Each axle is fitted with two wheels and one geared driving motor. The wheels have cast-steel centers and rolled-steel tires. The side frames are of the usual engine type and are made of cast steel.

The end frame, which is the bumper, consists of a heavy steel casting and is fastened to the side frames. The side and

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end frames are designed to withstand most effectively the shocks due to coupling, which are transmitted through them.

The weight of the cab and its equipment is transmitted to the wheels through a system of levers, hangers, springs, and saddles arranged so as to equalize the load between the axles and yet be very stiff so as to resist side motion and oscillation.

43. Dimensions and Weights.—The general dimensions of the locomotive are shown in Fig. 27. In this illustration, as will be noted, a minimum and a maximum height over the trolley collector are given. The reason for this difference in height is that the trolley wire must be much lower in the tunnel than it is in the open.

The weight of the locomotive complete with equipment is 67½ tons. The entire weight is carried by the six wheels, so that the weight at the rail head for each wheel is about 22,500 pounds.

EQUIPMENT

44. The equipment comprises all the apparatus used for the following operations: (1) To drive the train; (2) to control or effect correct combinations of the driving units to accomplish certain desired results, such as starting or accelerating a train; (3) to run at different speeds, to coast, or to reverse direction of train movement; (4) to retard the movement of the train or to hold it on grades by the application of power brakes; and (5) to heat the cab in cold weather and to dry the sand used in starting.

In general the equipment required to effect these operations consists of motors, motor control, master control, instruments, brakes, and heaters.

LOCATION OF APPARATUS

45. The inside apparatus of the locomotive is located at each side of a middle aisle that extends from end to end of the cab. This arrangement is the same as that in the New Haven locomotives and has the same advantages.

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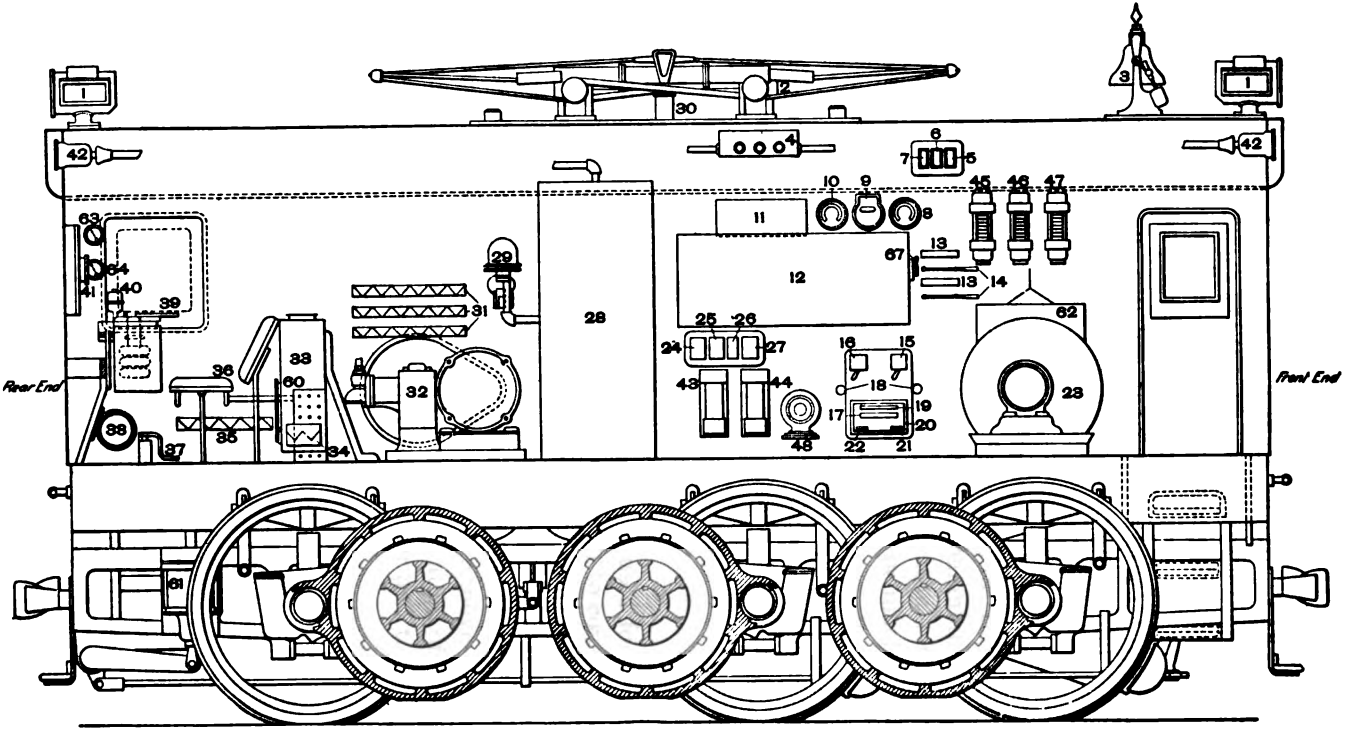

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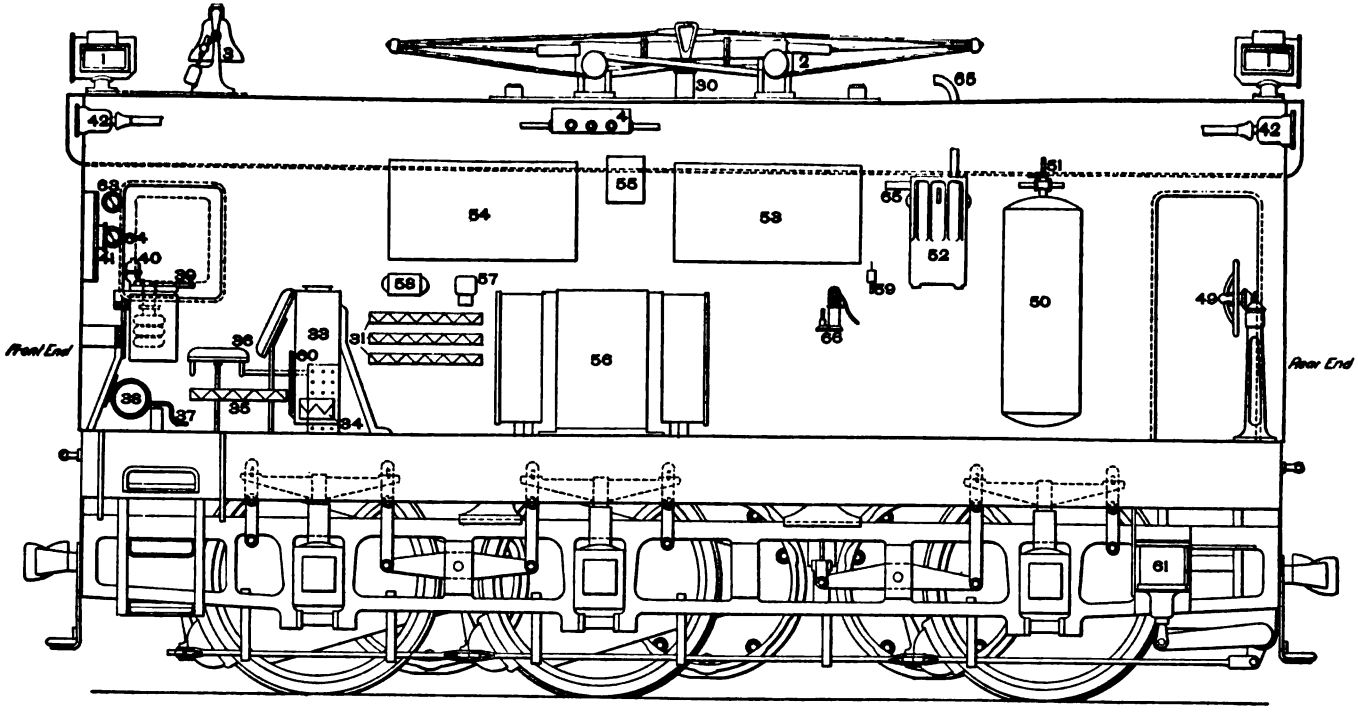

FIG. 28

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In Fig. 28 is shown each half of the locomotive in longitudinal section. To fix clearly in the mind the relation of these two sections of the locomotive, they should be considered in the same way as the similar illustration for the New Haven locomotive. Each piece of apparatus is shown in its relative position, and by use of the indicating numbers in the following list the name of each piece may be ascertained:

1, Headlights
2, Pantagraph trolley
3, Bell
4, Junction box
5, Front-headlight switch
6, Cab-light switch
7, Rear-headlight switch
8, Indicating wattmeter
9, Integrating wattmeter
10, Voltmeter
11, Control air reservoir
12, Unit switch group, No. 260
13, Cab-heater fuses
14, Cab-heater switches
15, Blower switch
16, Compressor switch
17, Blower fuse
18, Sand-heater switches
19, Compressor fuse
20, Fuse box
21, Sand-heater fuse
22, Light fuse
23, Blower
24, Battery switch
25, Battery switch
26, Direct-current motor-generator switch
27, Alternating-current motor-generator switch
28, Main air reservoir
29, Compressor governor
30, Whistle
31, Cab heaters
32, Air compressor
33, Sand box
34, Sand-box heater
35, Cab heater for motorman
36, Seat for motorman
37, Foot-pedals
38, Equalizing reservoir
39, Master controller
40, Brake valve
41, Ammeter
42, Train-line receptacles
43, Battery No. 1
44, Battery No. 2
45, *46*, *47*, Preventive coils
48, Motor-generator set
49, Hand-brake
50, Emergency air reservoir
51, Three-way valve
52, Line switch, No. 304
53, Unit switch group, No. 260–B
54, Unit switch group, No. 260–A
55, Train-line relay
56, Autotransformer
57, Overload relay
58, Line series-transformer
59, Magnet valves
60, Hand sander
61, Brake cylinders
62, Snow shutter
63, Brake-cylinder gauge
64, Main reservoir and train-line gauge
65, High-tension cable
66, Hand pump
67, Cut-out switches

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MOTORS

46. The motors are designed to operate on a single-phase, 25-cycle line and are of the 10-pole compensated type. Each is capable of developing 275 horsepower for 1 hour and 185 horsepower continuously. The motors are also designed to run with a maximum electromotive force of 275 volts across the terminals of each motor. Each locomotive is equipped with three motors. The motor is geared to the axle. It is swung from the axle on one side, and the nose on the other

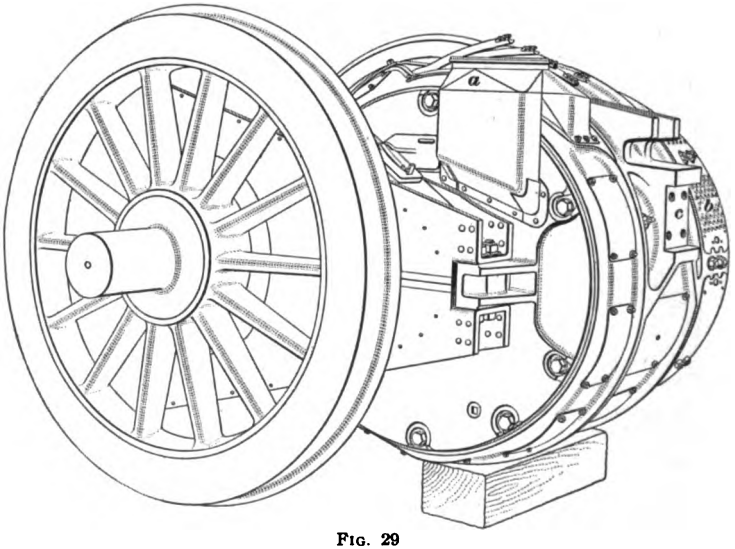

FIG. 29

side of the motor is fitted and bolted to a cross-bar that is supported from the truck frame by means of springs. The springs take up shocks due to irregularities of track and to the large torque necessary when starting.

A complete motor mounted on an axle and pair of wheels is shown in Fig. 29. The opening at the gear end, through which air to cool the motor is forced, is shown at *a*. This opening is fitted with a gauze of fine mesh to stop foreign material, such as waste, wood chips, etc., that may be drawn into the blowers at their intake, from getting into the motor

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windings. One commutator cover *b* is provided at each brush holder. These covers are perforated so that the air may discharge into the atmosphere after it has circulated through the motor and absorbed most of the heat generated by the motor. A cover is released by fitting a box wrench on the bolt head in the single recess at one end of the cover and giving the bolt a half turn. The cover may then be removed easily.

The machined nose, or lug, on the motor, to which the supporting channel is bolted, is shown at *c*.

MOTOR-CONTROL APPARATUS

47. Circuit-Breaker.—There is one circuit-breaker, or line switch, and this is in general similar to the alternating-current circuit-breaker on the New Haven locomotive. The St. Clair tunnel locomotive circuit-breaker, with the cover removed, is shown in Fig. 30. The contacts are located in the case shown at *a*, and this case is filled with oil so that any arc that may tend to form when the contacts are opened and while current is flowing may be promptly smothered. The case may be removed by loosening two screws, one of which is shown at *b*.

The switch is closed by compressed air acting on a piston attached to the moving arm. The piston is not shown in the illustration, because it is hidden by the top of the case. The compressed air is admitted to the cylinder by means of a small valve that is actuated by a magnet. The magnet is first energized by pressing the reset button on the master controller. After the switch is closed, an interlock *c*, which is attached to and moves with the moving arm, completes a circuit and thus keeps the magnet energized. This circuit passes through two relays. One of these relays interrupts the circuit if the locomotive looses power, and the other interrupts the circuit if the current taken by the motors exceeds a predetermined value. If either relay operates, the action of the operating magnet of the circuit-breaker allows the compressed air to escape from the cylinder and a powerful spring

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back of the piston then forces the circuit-breaker open. The circuit-breaker will then remain in the open position until the master-controller handle is returned to the off-position and the reset button is pushed. The circuit-breaker may be closed by hand by pressing downwards on the lever shown at *d*.

48. Transformer.—There is one autotransformer on this locomotive, and it reduces the voltage of 3,300 volts

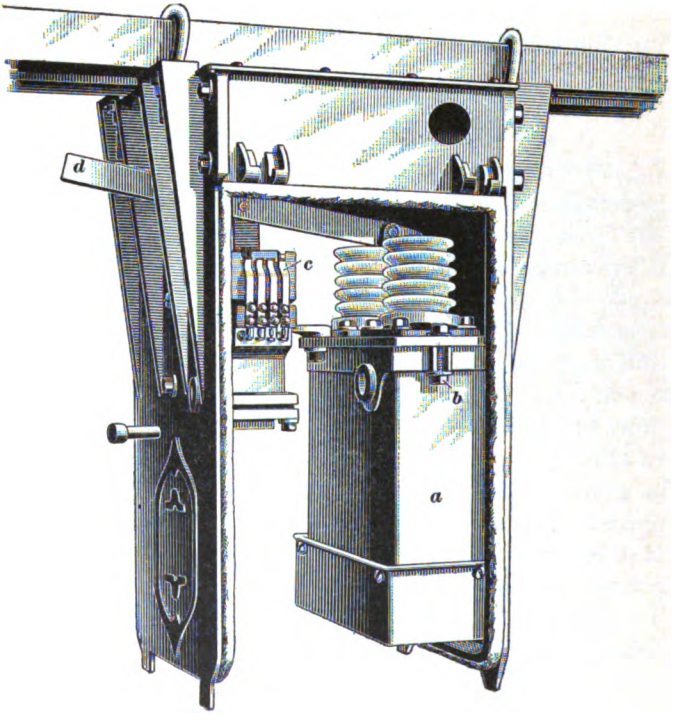

FIG. 30

between the trolley and the ground to that required for the motors. It is similar to the transformer shown in Fig. 10, and is of the air-blast type. This transformer receives the air from the same source as the motors and in the manner explained in connection with the transformers of the New Haven locomotive.

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49. Switch Groups.—There are three separate switch groups, one on one side and two on the other side of the locomotive cab, as indicated in Fig. 28. The switches are arranged so that the motors are connected permanently in multiple, and they have two distinct operations to perform as follows:

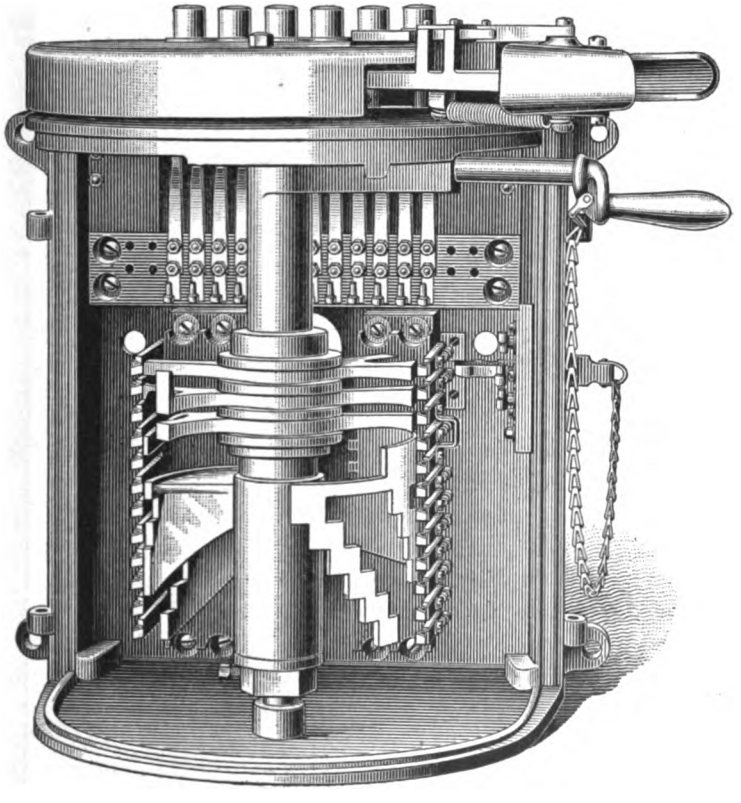

FIG. 31

1. They are arranged so that the closing of certain switches, by moving the master-controller handle, will connect the armature and field coils of each motor for train movement in a desired direction. If it is desired to reverse the direction of train movement, other switches in the same group may be

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made to reconnect the armatures and fields. These switches are similar to those shown in Figs. 11 and 12.

2. The switches of the two other groups are used to connect the motors progressively to various taps on the transformer, each tap giving on the motors a higher voltage than the preceding tap, so that the speed of the motors increases accordingly. These switches are similar to the alternating-current switches on the New Haven locomotive.

50. Preventive Coils.—There are three preventive coils. They are arranged on one side of the cab, at the end.

51. Pantagraph Trolley.—There is one pantagraph trolley. It is fitted to the top of the locomotive at the middle of the roof, and is used to collect the current from the trolley wire. The pantagraph trolley is shown raised and in contact with the wire in Fig. 26, and it may be raised in the same manner as the trolley of the New Haven locomotive.

52. Blowers.—The blowers are similar to those used on the New Haven locomotive.

53. Master Controllers.—The type of master controller used on the St. Clair tunnel locomotive is shown in Fig. 31. There is one of these controllers at each end of the locomotive. They serve the same purpose as the controllers used on the New Haven locomotive, and with the exception of the main drum and the number of push buttons, are constructed in practically the same manner. As the St. Clair tunnel locomotive operates on alternating current only, the main drum of the master controller has less contact rings and fingers, and these are arranged in a different order from those on the master controller of the New Haven locomotive. As there are no third-rail shoes, it is necessary to have only six push buttons instead of eight as on the New Haven locomotive.

By comparing the development of the master controllers on the New Haven locomotive with the development of those on this locomotive, as indicated in Fig. 32, the differences in constructive details may be noted.

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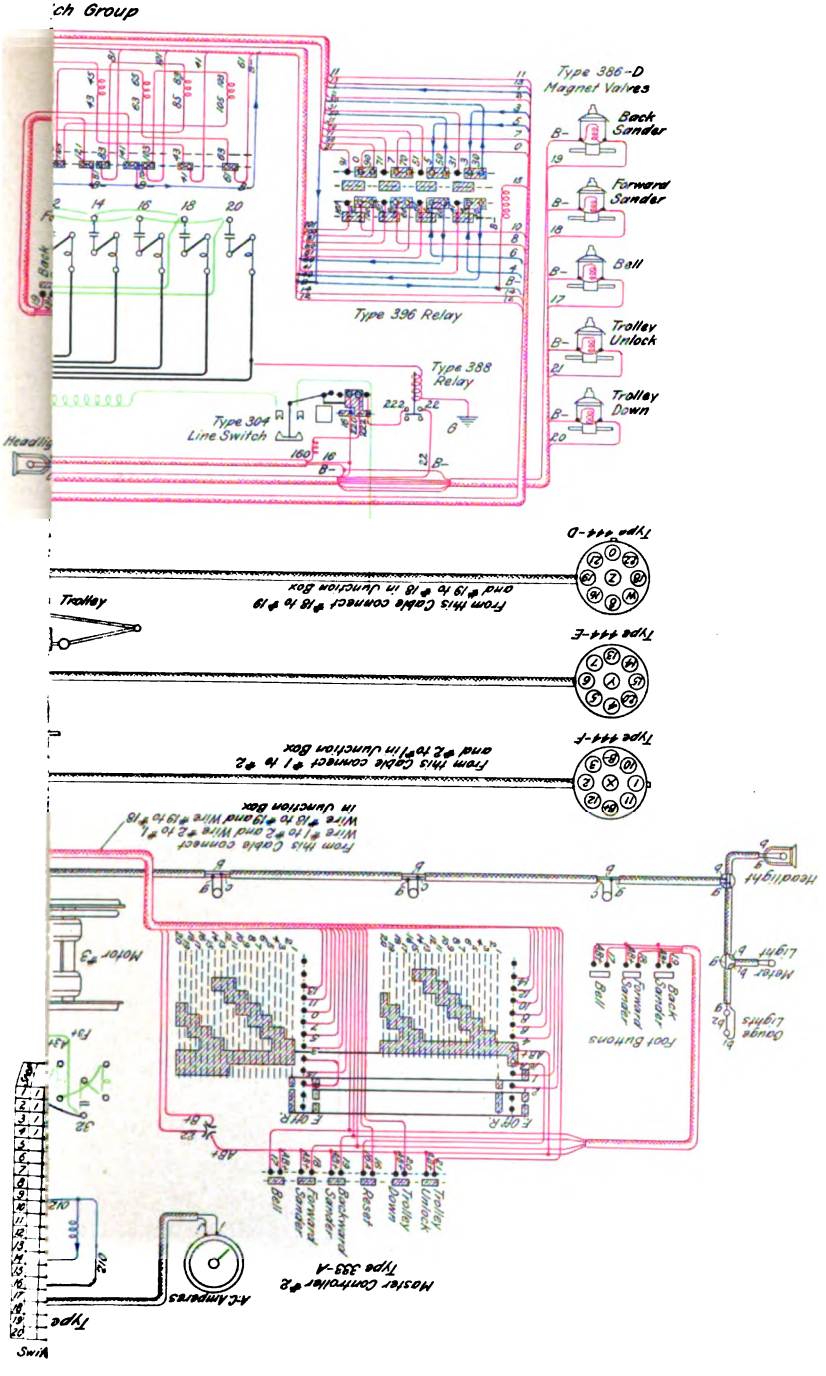

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54. Relays.—The St. Clair tunnel locomotive has three relays, two of which are used with the circuit-breaker, as already explained. The third relay (type 396 relay) is used to change automatically the connections of the master-control circuits, when the master controller is on notch *12*. This is done so that some of the control wires that were used before may be used later to operate other switches.

The operation of this relay is as follows: When the master-controller handle is on notch *12*, Fig. 32, contact finger *15* is in contact with the corresponding ring on the main drum. The drum is connected to the positive side of the storage battery. By following wire *15*, it will be found that it termi-

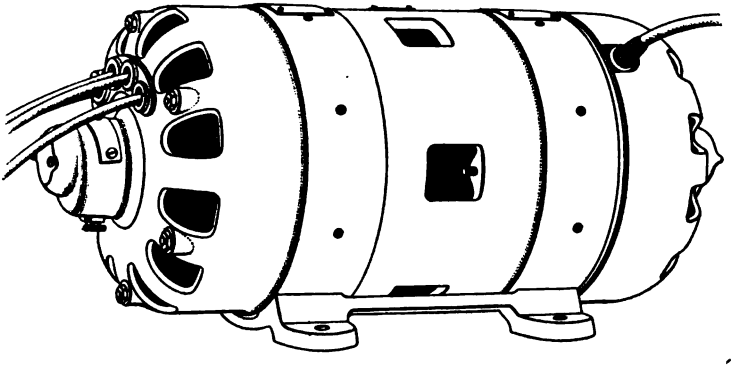

FIG. 33

nates at one end of the operating magnet of the type 396 relay. The other side of the magnet is connected to the negative side of the battery, so that the magnet is now energized and actuates a valve, thus allowing compressed air to enter a cylinder and effect the movement of a piston that turns the relay. When the master-controller handle passes notch *12* in returning to the off-position, the drum is returned to its first position by a spring.

55. Train-Line Cable.—The train-line cable comprises the cable and the connectors used to join the master-control circuits of two or more locomotives coupled together so that they may be operated from the master controller of

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the forward locomotive. The cable is of the ordinary multicore type, and has the same number and the same kind of connector sockets and jumpers as the New Haven locomotive.

56. Storage Battery.—The storage battery is an exact duplicate of that used in the New Haven locomotive.

57. Motor Generator.—The batteries are charged from a small motor-generator set, as shown in Fig. 33. An alternating-current motor drives the generator, which supplies direct current at about 20 volts.

58. Instruments.—An ammeter is installed at the driving end of the cab, being placed in front, but a little to one side, of the motorman's seat, as indicated in Fig. 28. This ammeter indicates the current taken by the motors when accelerating a train from rest or when running at a settled speed.

Near the middle of the cab are installed a voltmeter, an indicating wattmeter, and an integrating wattmeter. The voltmeter indicates the voltage across the motors, which are connected in multiple; the indicating wattmeter indicates the electric power that the motors are using at any time; and the integrating wattmeter records the total electrical energy used by the locomotive.

ELECTRIC CIRCUITS

59. A complete wiring diagram for this type of locomotive is shown in Fig. 32. The schematic arrangement of the electrical apparatus and a table of the sequence of the closing of the switches corresponding to each notch on the master controller are also shown. The first three notches are for switching only, and are not intended as running positions. The color scheme of Fig. 32 is the same as that used for the circuits in Fig. 22. The blue lines, Fig. 32, indicate the master-control circuits that are conducting currents when the master controller is on the fourth notch, and the arrowheads indicate the direction of flow of current. Circuits or wires that lie in the same direction, and either originate or terminate in the

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same piece or adjacent pieces of apparatus, are shown accumulated into a multicore cable, but no confusion will arise if it is borne in mind that each circuit is indicated by a number.

For example, consider circuit *5*, which starts at contact finger *5* of the master controller, and goes through the junction box, type 427, to the relay, type 396. When this current leaves the relay, it is given the number *50*, and circuit *50* goes to one side of the magnet for operating unit switch *3*. When leaving the magnet, this circuit is given the number *52*, and the circuit now goes to the interlock on unit switch *7*. When leaving the interlock, it is given the number *54*, and the circuit now goes to the interlock of unit switch *11* and thence to a common wire $B-$ connected to the negative side of the battery.

All terminals in the junction box having the same number are actually connected together; but they are not so shown in the illustration, as confusion would be created, owing to the large number of lines. In Fig. 32, the green lines indicate the power circuits that are active when the master controller is on the fourth notch.

BRAKES AND HEATERS

60. The brakes are the exact duplicates of those used on the New Haven locomotive. The electric heaters used in the cab, however, are of the type ordinarily used in heating street cars. The service that these locomotives perform makes it important to have a free and ample flow of sand. To assure this effect, each sand box is fitted with a set of special heaters that keep the sand dry at all times.

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NEW YORK CENTRAL AND HUDSON RIVER RAILROAD LOCOMOTIVE

SERVICE CONDITIONS

61. After a careful study of the conditions under which the trains of the New York Central and Hudson River Railroad must operate, it was decided by that company to equip the system for operation with direct current at 600 volts. In this system, an insulated third rail, connected to the positive side of the circuit, is erected outside of the gauge line for each track and is used as a collector rail. The track rails are bonded one to another and are used as the negative side of the circuit.

The power station is equipped with machines that generate alternating current at high voltage, and this current is transmitted by cables to substations installed at frequent intervals along the right of way. The substations are equipped with static transformers, which reduce the voltage to that required by rotary converters. These converters, in turn, change the alternating current into direct current at 600 volts for the collector rails.

The local train service is maintained by multiple-unit trains and the main line, or express service, by electric locomotives. These electric locomotives haul the trains between Grand Central Station and points beyond the city limits; but beyond these points, the express service is maintained by steam locomotives.

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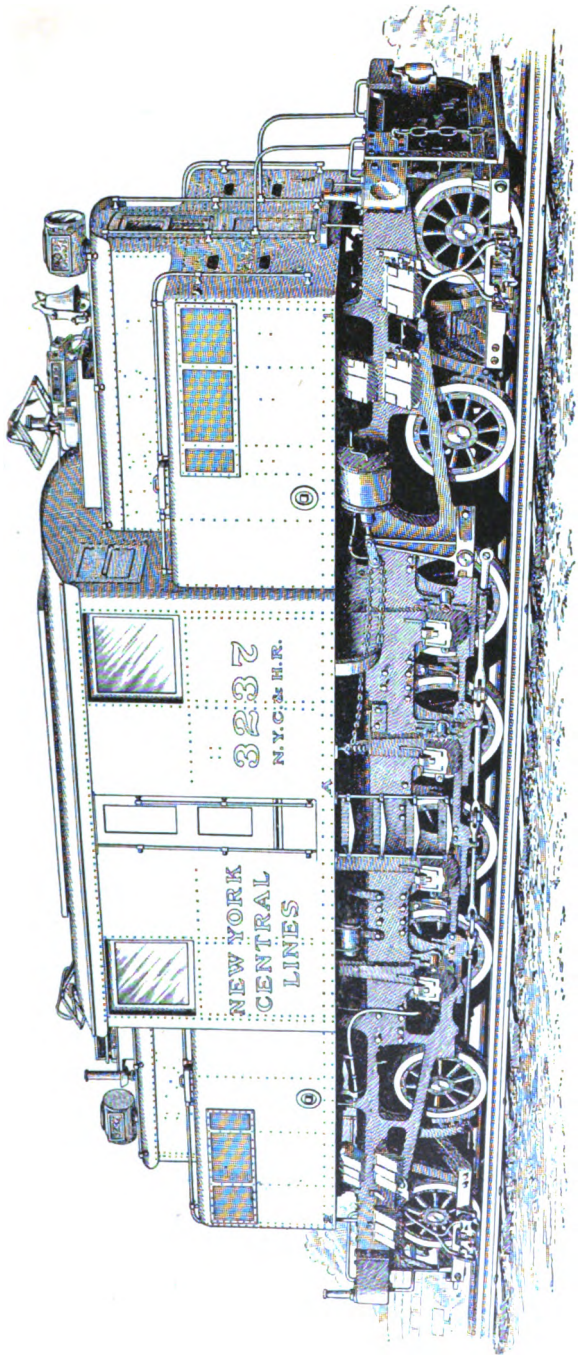

FIG. 34

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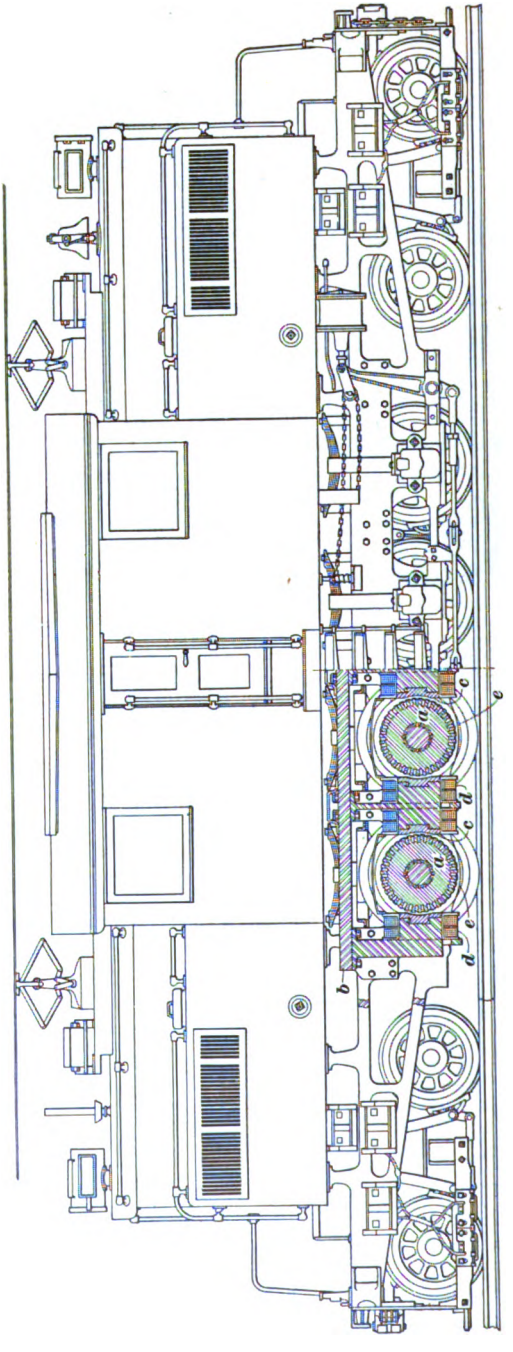

FIG. 35

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GENERAL DESCRIPTION OF LOCOMOTIVE

62. The New York Central locomotive, as shown in Fig. 34, is made up principally of three parts, a cab, a truck,

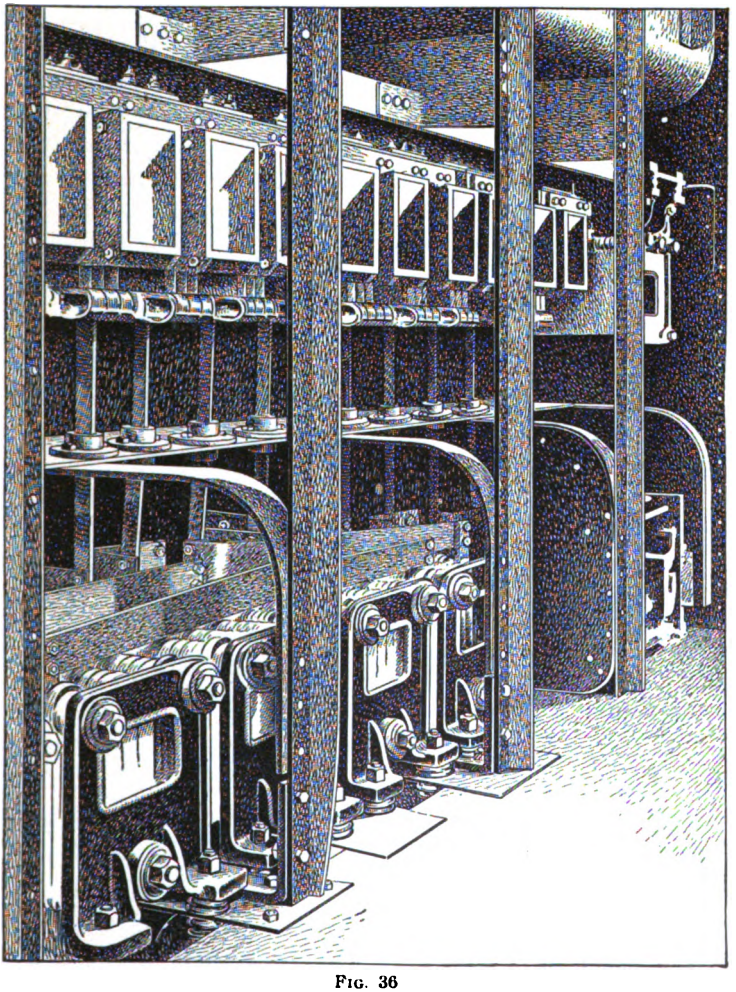

FIG. 36

and the equipment. In Fig. 35 is shown the side elevation of the locomotive and a cross-section of a portion of the truck

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and motors. Reference to the lettered parts will be made later.

63. Cab.—The cab is composed of a stout skeleton of **Z** bars and angle irons. These are securely fastened together by means of gusset plates and rivets. This skeleton is covered by sheet-steel plates, which are riveted to the skeleton.

The cab is provided with a large central compartment for the use of the motorman. In this compartment is fitted the measuring instruments and the apparatus that must be manipulated when operating the locomotive, as, for instance, the master controllers, the sander operating switches, the bell ringer, and the engineer's brake valve. In addition to these devices, the air compressor and steam heaters are placed in this compartment. A master controller and an engineer's brake valve are installed at each end of this compartment in diagonally opposite corners, so that the motorman may drive the locomotive in either direction and have a clear lookout ahead. A passageway connects the central compartment with a door at each end, and on each side of the front and rear passages are compartments into which are fitted the control apparatus and resistances.

In Fig. 36 is shown one of the four end compartments, indicating the positions of a group of contactors with sets of rheostats installed immediately below them. Each side of the central compartment is fitted with a sliding door, and each corner has a front window and a side window. The windows are of the drop type. At the end of each passageway is a swinging door, and ventilating panels to carry off the heat generated in the rheostats, contactors, etc. are provided on the side of each end compartment. The central compartment is fitted with a ventilator in the roof, and an overhead collector shoe is fitted to the roof over the passageway, at each end.

64. Under Frame.—The frame consists of center and side channels that are secured together by means of crossties, gusset plates, and knee braces. The end frames consist of channels.

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65. Trucks.—The main truck has four driving axles, and each axle is fitted with two wheels and a gearless driving motor. The wheels have cast-steel centers and rolled-steel tires.

The side frames are of the usual engine type and are made of cast steel. They are bolted to and tied together by a set of steel castings that form the frames for the motors, as indicated in Fig. 35. There are projections, or saddles, above each side frame to which the cab is fastened. The end frame, or bumper, consists of a heavy steel casting that is fitted and secured to the side frames. An automatic car coupler is fitted to each bumper, and each coupler is fitted with a Westinghouse friction draft gear. At each end, a four-wheel

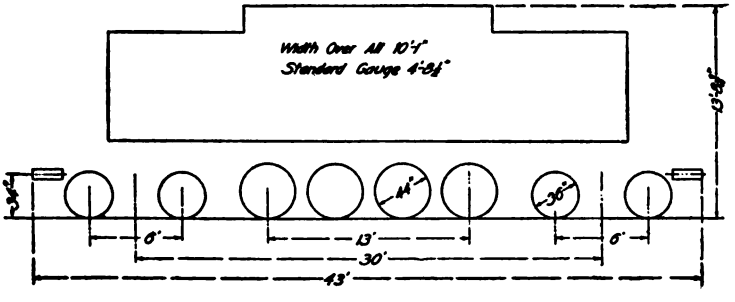

FIG. 37

bogie truck is fitted, so as to prevent nosing. By *nosing* is meant the movement of the front end of the locomotive from side to side. It is especially liable to occur when the locomotive is rounding a curve.

66. Dimensions and Weight.—The general dimensions of the locomotive are indicated in Fig. 37. The weight of the locomotive, complete with equipment, is 115 tons. The total weight on the drivers is 70 tons, which is carried by eight driving wheels. The weight at the rail head for each driving wheel is 17,500 pounds, and that at the rail head for each wheel on the bogie truck is about 11,250 pounds.

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EQUIPMENT

67. The equipment of the New York Central locomotive comprises all the apparatus used for the following operations: (1) To drive the train; (2) to control or to effect correct combinations of the driving units to accomplish certain desired results, such as starting or accelerating a train; (3) to run at different speeds, to coast, or to reverse the direction of train movement; (4) to retard the movement of the train or to hold it on grades by the application of power brakes; and (5) to generate or make steam for heating the train in cold weather.

A detailed description of the apparatus will be given, but, in general, the equipment to effect all the preceding operations is as follows: Motors, motor control, master control, instruments, brakes, and oil-fired boilers. The contactors, reverser, and rheostats are arranged so that the sets at each end of a locomotive are connected to the two nearest motors.

MOTORS

68. Frame.—The motors are of the gearless type, with the armature mounted or pressed directly on the axle without the intervention of a spring-borne quill. The motor frames form a part of the truck frame. The normal capacity of each motor is 550 horsepower, so that the normal capacity of the locomotive is 2,200 horsepower.

A cross-section of the four motors is illustrated in Fig. 35, the armatures being shown at *a*; the frame, at *b*; the pole tips, at *c*; and the field coils, at *d*. The motor construction is shown in greater detail in Figs. 38 and 39. In Fig. 38 is shown a horizontal section of a motor, and in Fig. 39, a cross-section.

As indicated in Fig. 35, the motor frame is continuous from end to end, and the pole pieces are bolted to the motor frame and to the side frames of the truck. With a motor having the armature rigidly attached to the axle and the poles rigidly attached to the truck frame, there is a vertical

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movement between them. This movement is due to the wheels following irregularities in the track, to the swaying of the truck, or to the settling of the truck when rounding a curve at high speed. By referring to Fig. 39, it will be seen that this movement is provided for by having a large air gap and a pole tip that is only slightly curved; also, the diameter of the armature is less than the width between the straight faces of the pole tips. This arrangement allows an axle, with the armature and the wheels, to be lowered and removed

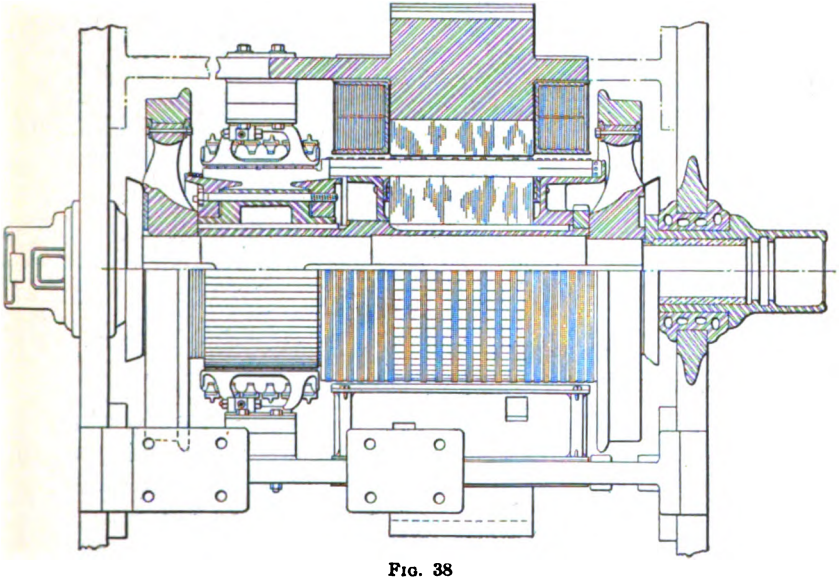

FIG. 38

from the locomotive without disturbing any other part of the motor.

69. Armature.—As shown in Fig. 38, the armature is built up on a cast-steel spider, while the commutator is built up on a separate cast-steel spider that is keyed to the armature spider. After the armature is completed, it is pressed on the axle before the second wheel is pressed on.

The entire motor is quite open and is therefore supplied at all times with plenty of fresh, cool air. This arrangement

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gives moisture, snow, and dirt easy access to the parts, but successful operation has proved that they are not harmful. However, a brass screen *e*. Fig. 35, is fitted under each armature, from pole to pole, and thus prevents large pieces of hard foreign material from getting into the parts of the motors.

There are two brush holders, one at each end of a horizontal diameter of the commutator. They are attached to supports

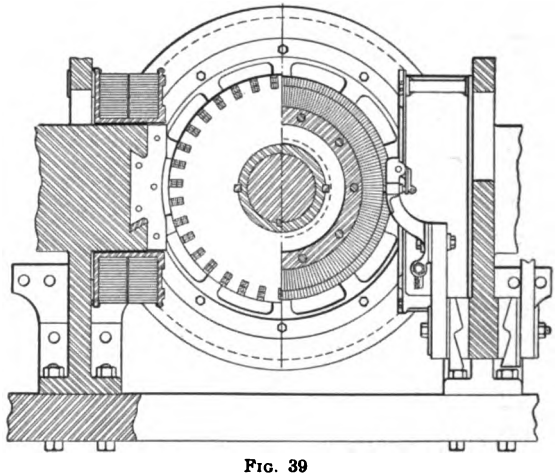

FIG. 39

carried from the journal boxes, so that they have the same movements as the armature and thus remain in the same position on the commutator. This construction is necessary in order to prevent sparking and flashing of the motor.

MOTOR-CONTROL APPARATUS

70. Contactors.—There are four groups of contactors, one in each of the end compartments, making a total of fifty-three contactors. These contactors have the following operations to perform:

1. Certain contactors are used to cause reversal of the direction of rotation of the motors.

2. Certain contactors are closed and connect the four motors in series with a resistance, and then other contactors close progressively and cut this resistance out of circuit.

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3. Certain contactors connect the four motors into two parallel groups, each group having two motors connected in series and each motor group being connected in series with resistance. In this operation, some of the contactors previously closed remain in that position, but all the resistance contactors are opened. The resistance contactors close progressively and cut the resistance out of circuit.

4. Certain contactors connect the four motors in parallel, each of the motors being connected in series with resistance. In this operation, some of the contactors previously closed remain in that position, but all the resistance contactors are opened; they then close progressively and cut out the resistance.

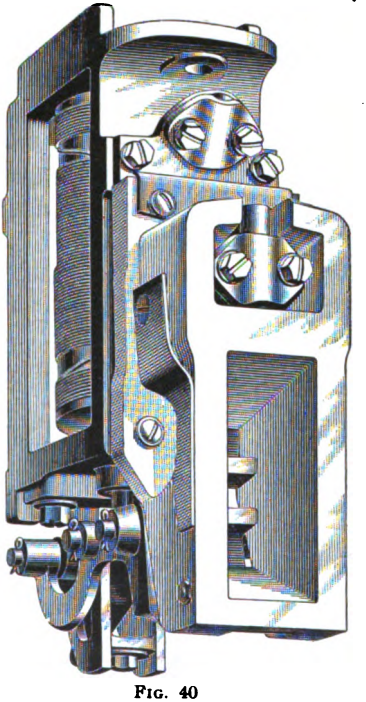

FIG. 40

This arrangement for accelerating or starting—where the four motors are first connected four in series; next, two groups in parallel, each group having two motors in series; third, all four motors in parallel — results in the more economical operation of the train, especially where there are frequent stops, as considerably less power is wasted as heat in the resistance.

In Fig. 40 is shown a single contactor. The detail construction and operation of a contactor of this type is described and explained in *Multiple-Unit Systems*, Part 1. Practically the only difference between the contactor there described and the contactor used on the New York Central locomotive is in the contact tip; the former contactor has single contact tips, while the locomotive contactor, since it must conduct a much greater current, has double contact tips.

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As indicated in Fig. 36, the contactors are attached to, but insulated from, the angle-iron supports that form a part of the cab construction.

71. Reversing. — The direction of rotation of the motors, and, therefore, the direction of train movement, is regulated by certain of the contactors that change the armature connections and thus reverse the direction of the rotation of the armatures.

72. Rheostats.—The rheostats, which are connected in the motor circuits when accelerating, are made up of cast-iron grids that are assembled into frames of convenient size. These frames are arranged in four groups, each group being placed under the contactors in the four compartments at the ends of the locomotive. The frames are securely fastened to the cab framing. In Fig. 36 is shown the rheostats, the method of fastening them to the framing, and the copper-bar connections between the rheostat grids and the contactors.

73. Main Switch.—A large knife switch with a quick-break attachment is connected in the circuit between the collector shoes and shoe fuses and the control and motor circuits. This switch is used normally to open the circuit so that all the control apparatus may be *dead*, or without power, when inspecting or repairing parts. In case of emergency, the switch may be opened when the motors are using power.

The switch itself is installed within a metal box that is lined with fireproof material. The blade of the switch is connected by links that pass through an opening in the cover of the box to a lever, the movement of which either opens or closes the switch. The lever is actuated by hand.

74. Motor Cut-Out Switches.—A plain knife switch is connected in the circuit between the control apparatus and each motor, so that any one or more motors may be cut off from the other apparatus should it be necessary.

The switches for motors Nos. *1* and *2* are mounted on the same insulating base, as are also the switches from motors Nos. *3* and *4*. These switches are not enclosed, as they are

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never to be opened when the motors are taking power. Each switch is fitted with a small auxiliary contact that is connected in the master-control circuits in such a manner that a false grouping of contactors and motors cannot take place when any of the switches are open. This contact makes sure that all the motors not cut out will be connected in parallel.

75. Collector Shoes.—As indicated in Fig. 34, the third-rail collector shoes are attached to each bogie truck. There are four sets of these collector shoes—two on each side of the locomotive.

As shown in Fig. 41 the collector shoes are insulated from the truck by means of a wooden block *a*. The shoes *b* are free to turn on a spindle, which is pinned to the bracket *c*.

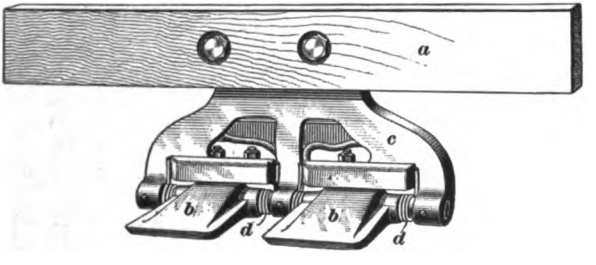

FIG. 41

Springs *d* having one end fastened to the spindle and the other end pressing against a lug on the shoe, force the shoe upwards so that it bears against the under-running third rail with considerable pressure. In order to allow the shoe when not bearing on the third rail to engage properly with the end of the third rail, the bracket is provided with a stop that prevents the shoe from being raised too high.

As indicated in Fig. 34, an overhead collector shoe is supported from the cab roof at each end of the locomotive. These collectors are used when complicated cross-overs make it necessary to discontinue the third rail for a long distance, principally in the yards at Grand Central Station.

These collector shoes are raised by compressed air, which is controlled by a valve near the master controller. The shoes

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remain raised and in contact with the overhead rail as long as the motorman holds the valve in the corresponding position. As soon as the valve handle is released, a spring returns it to the off-position and the shoes drop.

76. Bus-Line.—All the collector shoes on a locomotive are connected to a common bus-line that extends from end to end of the locomotive and terminates in three-point receptacles. When two or more locomotives are coupled together, the bus-line may be made continuous by connecting adjacent receptacles together with a three-point, double-end jumper, each end of which fits into one of the receptacles.

77. Fuses in Power Circuits.—All power circuits are amply protected by fuses, and each collector shoe, either third rail or overhead, is protected by a double fuse.

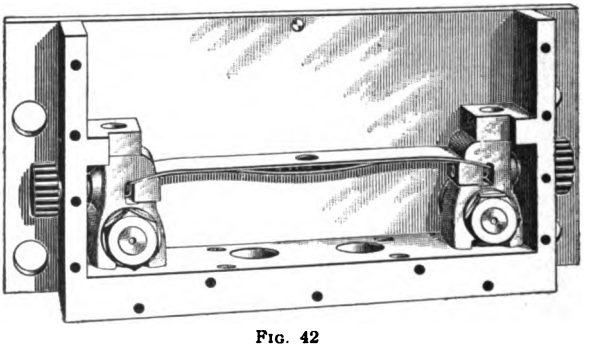

FIG. 42

These fuses are shown in Fig. 42. One side of the enclosing box has been removed in order to show the fuse and fuse terminals. These fuses are made of a copper ribbon that is enclosed on all but one side by fireproof material. The box has fastened to it pieces of sheet steel that form the poles of an electromagnet. These are arranged so as to disrupt magnetically the arc formed by the melting of the fuse. These fuses are located immediately over the third-rail collector shoes and on the roof immediately in front of the overhead shoes.

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Each motor circuit is protected by a single fuse of the same type as that used for the collector shoes. These fuses are located immediately over the fuses for the third-rail shoe.

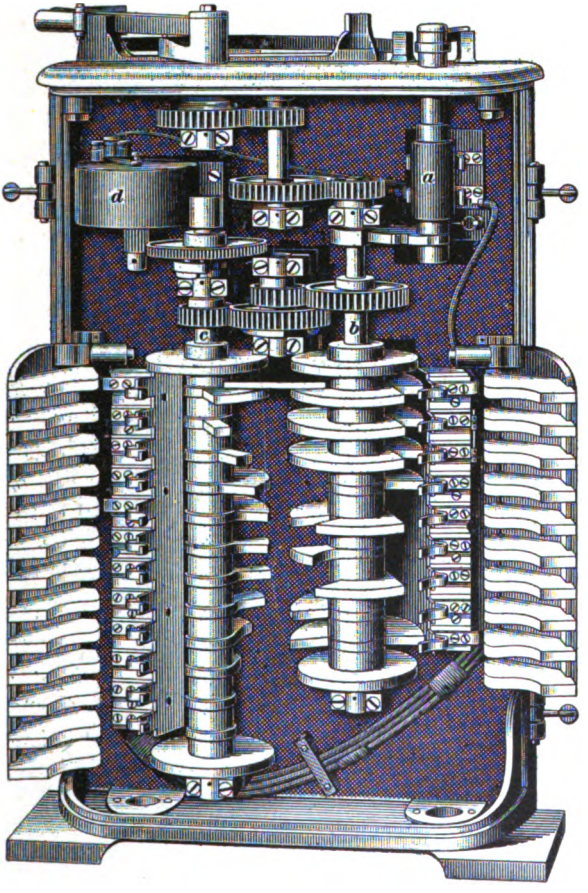

FIG. 43

The position of these fuses may be readily seen by referring to Fig. 35.

78. Master Controllers.—In the New York Central locomotive there are two master controllers that are

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exact duplicates of each other. They are of the drum type and are located as previously explained.

In Fig. 43 is shown the front of a master controller of the general type used on these locomotives. The cover is removed and the arc shields are open. There are three drums, namely, a *reverse drum a*, which is operated by a single handle that establishes circuits that operate the reversing devices, and two *control drums b* and *c*, which are operated by one handle through a train of gears. Drum *b* establishes circuits that operate the motor contactors necessary to effect the three combinations of motors, namely, series, series-parallel, and parallel. Drum *c* establishes circuits that operate the resistance contactors. These contactors cut out the motor resistance when accelerating. Since drum *c* has to cut out the motor resistance three times, corresponding to the three motor combinations, the gears are so arranged that it rotates nearly three times as fast as drum *b*.

In some of the controllers there is a current-limiting device *d* that is so arranged that it stops the rotation of drums *b* and *c* when the current taken by the motors exceeds a predetermined amount. As indicated in Fig. 43, the current-limiting device is actuated by a magnet, and this magnet is energized by the action of a current-limit relay, if such a device is incorporated in the locomotive wiring.

The reverse, motor, and resistance drums are mechanically interlocked in such a manner that the former drum cannot be moved unless the two latter drums are in the off-position; and the two latter drums cannot be moved unless the former drum is in the position of forward or reverse running.

The notching plate for the handle-operating drums *b* and *c* has an off-position and twenty-four notches for operation. These notches are arranged in three groups, the first group containing ten notches and each of the last two groups containing seven. The first ten notches are intended for operating with all motors in series, the tenth notch being a running position with all motor resistance cut out. The next seven notches are intended for operating with two motors in series in each group, and these two groups in parallel, the last notch of this

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group, the seventeenth from the off-position, being a running position with all motor resistance cut out. The next seven notches are intended for operating with all motors in parallel,

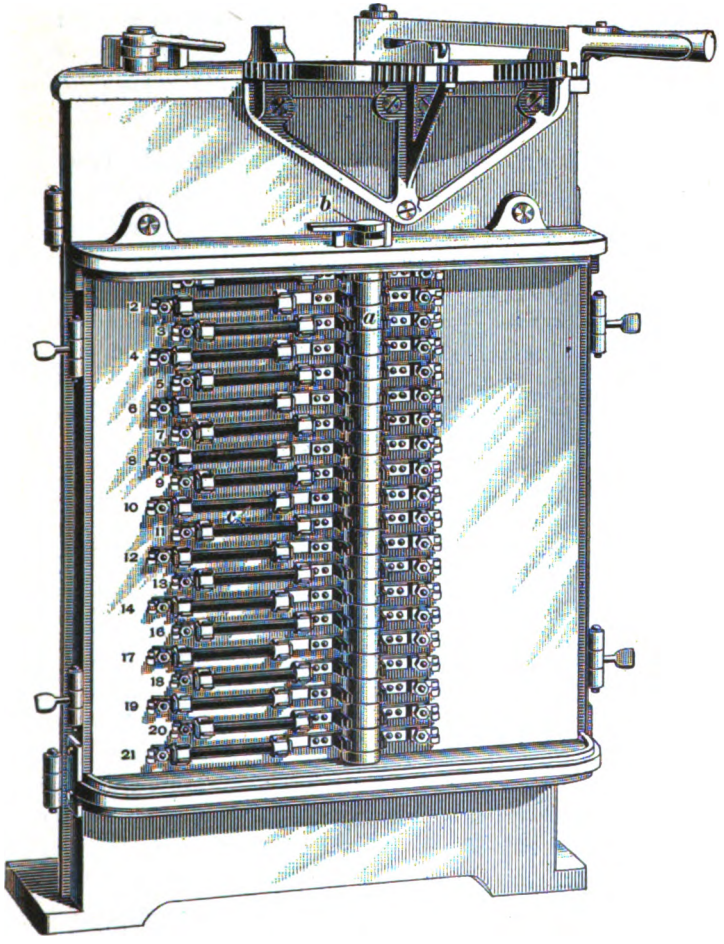

FIG. 44

the last notch of this group, the twenty-fourth from the off-position, being a running position with all motor resistance cut out.

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79. Master-Controller Switch.—A small knife switch is connected in the circuit between the line and the master controller. This switch is used to isolate the master controller contacts from the line for the purpose of inspection or for the renewal of a fuse. This switch is located at one end of the locomotive. One switch serves both master controllers, and it has to be closed or opened to supply power to or isolate either master controller.

80. Train-Line Cable and Connectors.—The train-line cable and connectors are very much like those described in *Multiple-Unit Systems*, Part 1, the chief point of difference being that in those for the locomotive there are twenty contact points.

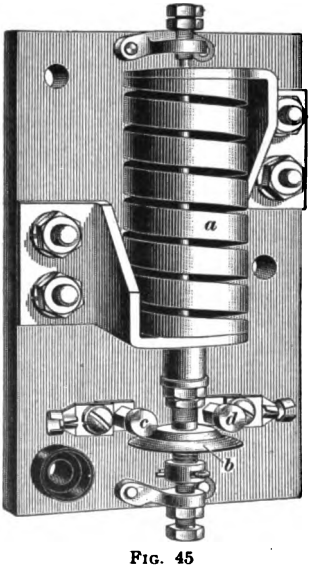

FIG. 45

81. Connection Boxes and Control Cut-Out.—In Fig. 44 is shown the back of a master controller and the control cut-out box attached to it. The second master controller in each locomotive has a plain connection box without the control cut-out.

Referring to Fig. 44, the control cut-out drum is shown at *a* and the handle by which it may be rotated, at *b*. The train-line and the master-control cable to all operating circuits are connected through this drum to both master controllers. The drum may be turned so that both master controllers will be completely isolated from the master-control circuits for inspection or test purposes.

All the train-line cables are connected to the numbered terminals indicated at the left in Fig. 44. All the control circuits are protected by enclosed fuses *c*, which are connected between the train line terminals and the cut-out drum.

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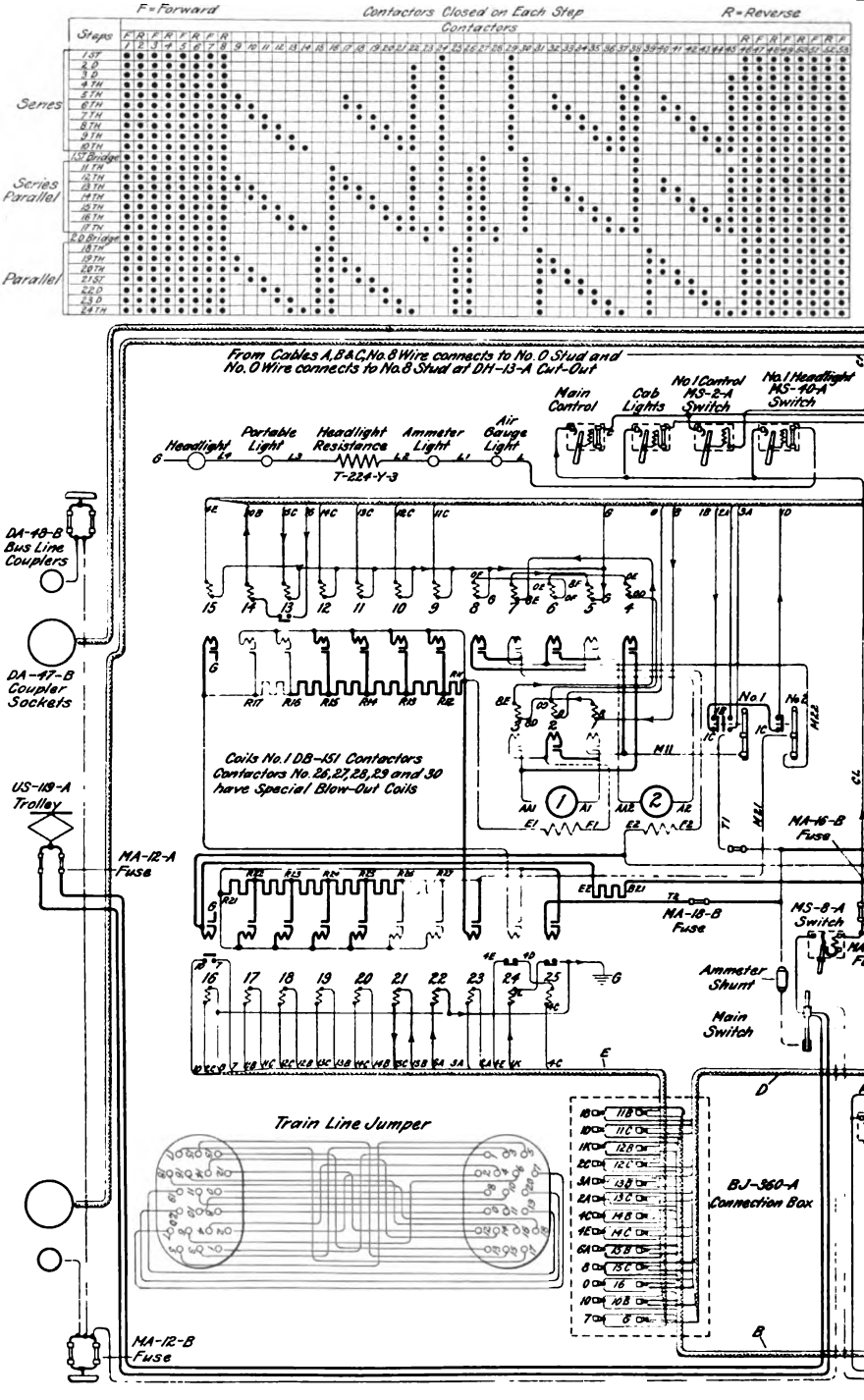

FIG

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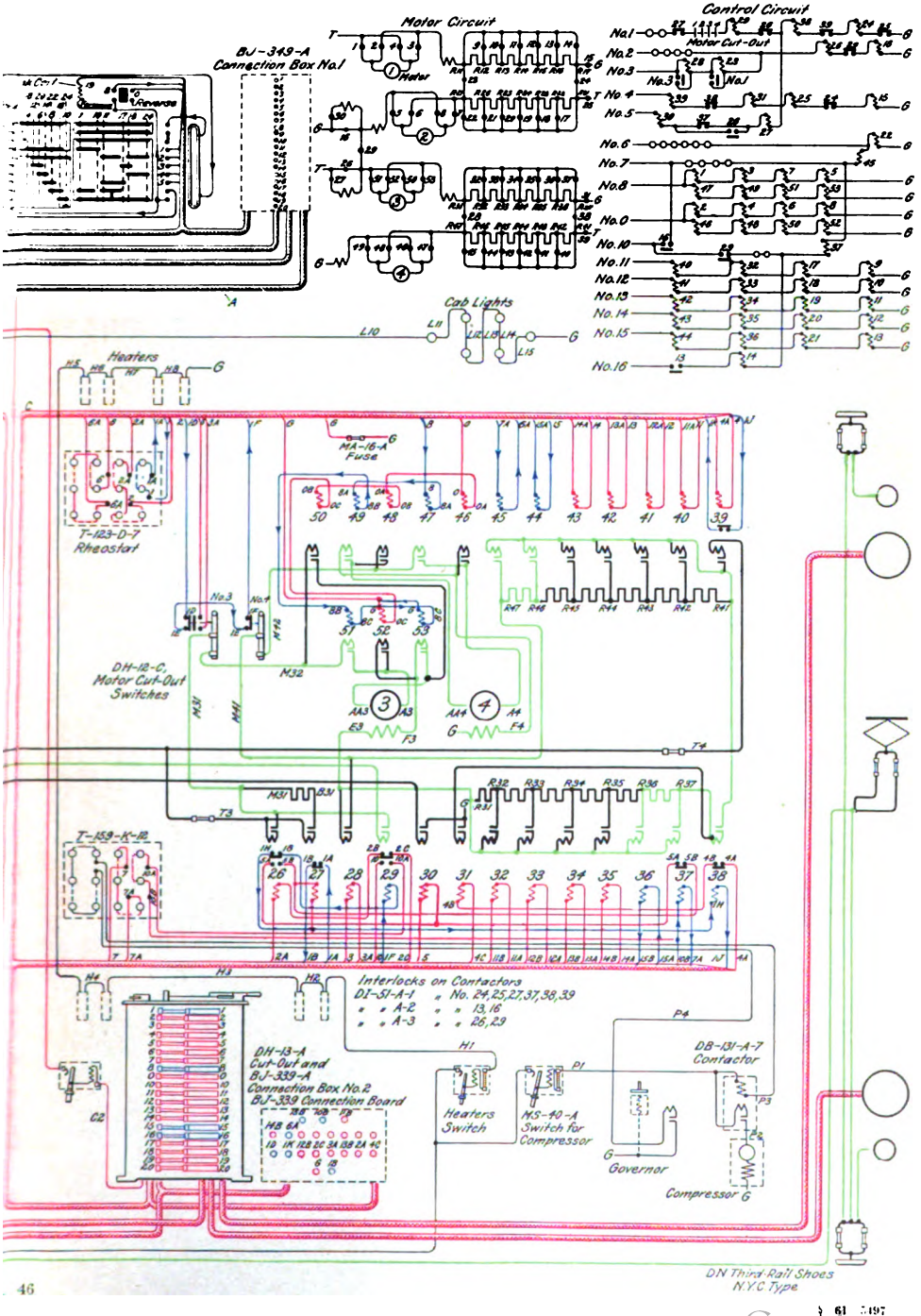
Wiring For Sprague-General Electric Type M Control With C-27-C Controllers And Four Motors
N.Y.C. & H.R.R.R. Locomotive



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82. Current-Limit Relay. — The type of current-limit relay used on some of the New York Central locomotives is shown in Fig. 45. The operating coil *a* is connected in the circuit of motor No. *2*. The contact disk *b* hangs below contact pieces *c* and *d*, but does not touch them when the current flowing in the circuit of motor No. *2* is not excessively high. When motor No. *2* takes more than a certain amount of current, the plunger is lifted and the disk bridges the contacts *c* and *d*. In this way is established a circuit that energizes the clutch magnet in the master controller and thus arrests the movement of the master-controller handle until the current has lowered to the desired amount. When the current has become low enough, the disk will drop and interrupt the circuit through the clutch magnet. The controller handle can then be advanced.

83. Instruments.—Ammeters are arranged in a convenient location so that the motorman may see how much current the motors are taking. The ammeter readings act as a guide when accelerating the train.

ELECTRIC CIRCUITS

84. In Fig. 46 is shown a complete wiring diagram of the New York Central type of locomotive. The color scheme of this diagram is the same as that of the other wiring diagrams used in this Section. The power and master-control circuits have been traced for the full series-connections of the motors, which condition occurs when notch No. *10* of the master controller is active.

When tracing either the power circuits or the master-controller circuits for any position of the operating drums of the controller, it is well to refer to the table of the sequence of switches and to note the contactors that are closed on that position of the controller as well as the positions of the corresponding interlocks.

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BRAKES AND HEATERS

85. With the exception of the air compressor and governor, the air-brake equipment of the New York Central locomotive is practically the same as that of the New Haven locomotive. The air compressor of the New York Central loco-

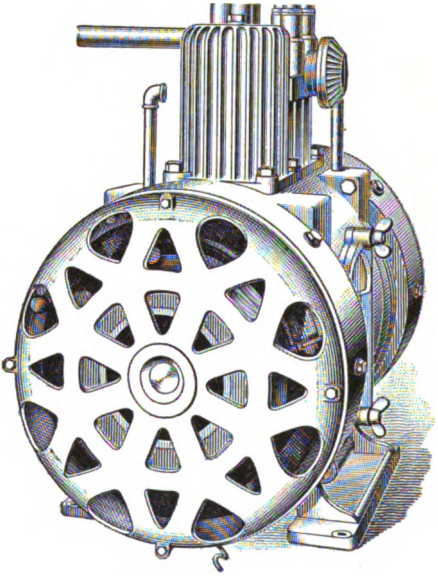

FIG. 47

motive is illustrated in Fig. 47, the motor end of the set being shown at the left. The motor shaft is connected directly to the crank-shaft of the compressor, and the cylinders are vertical.

The locomotive and the train are heated by steam that is generated in a steam boiler like the one installed on the New Haven locomotive.

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BALTIMORE TUNNEL AND SIDE-ROD LOCOMOTIVES

BALTIMORE AND OHIO RAILROAD—BALTIMORE TUNNEL LOCOMOTIVE

86. Electric locomotives are used on the Baltimore and Ohio Railroad to haul trains through the tunnel under the city of Baltimore. In the system installed, direct current at from 600 to 650 volts is collected from a third rail located at one side of each track.

In Fig. 48 is shown a complete locomotive comprising two units. The cab is built up of steel plates that are attached to a skeleton of angle irons and **Z** bars. The side and end frames are made of heavy steel castings and are fitted and bolted together, forming a structure that will withstand severe shocks. The couplers are fitted to the end frames.

There are two trucks, each having two axles, and each axle is fitted with a geared motor of 225 horsepower. The Sprague-General Electric type M control system as used on this locomotive is, in general, similar to the control system used on the New York Central locomotive.

SIDE-ROD LOCOMOTIVE

87. In the types of locomotives just described, the center of gravity is low owing to the location of the motors on the trucks. Thus, when rounding curves, the side thrusts of the locomotives on the rail head cause wear on this part and set up severe stresses in the rail.

In the **side-rod locomotive**, Fig. 49, the motors are mounted on the top of the truck frame and project into the

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FIG. 48

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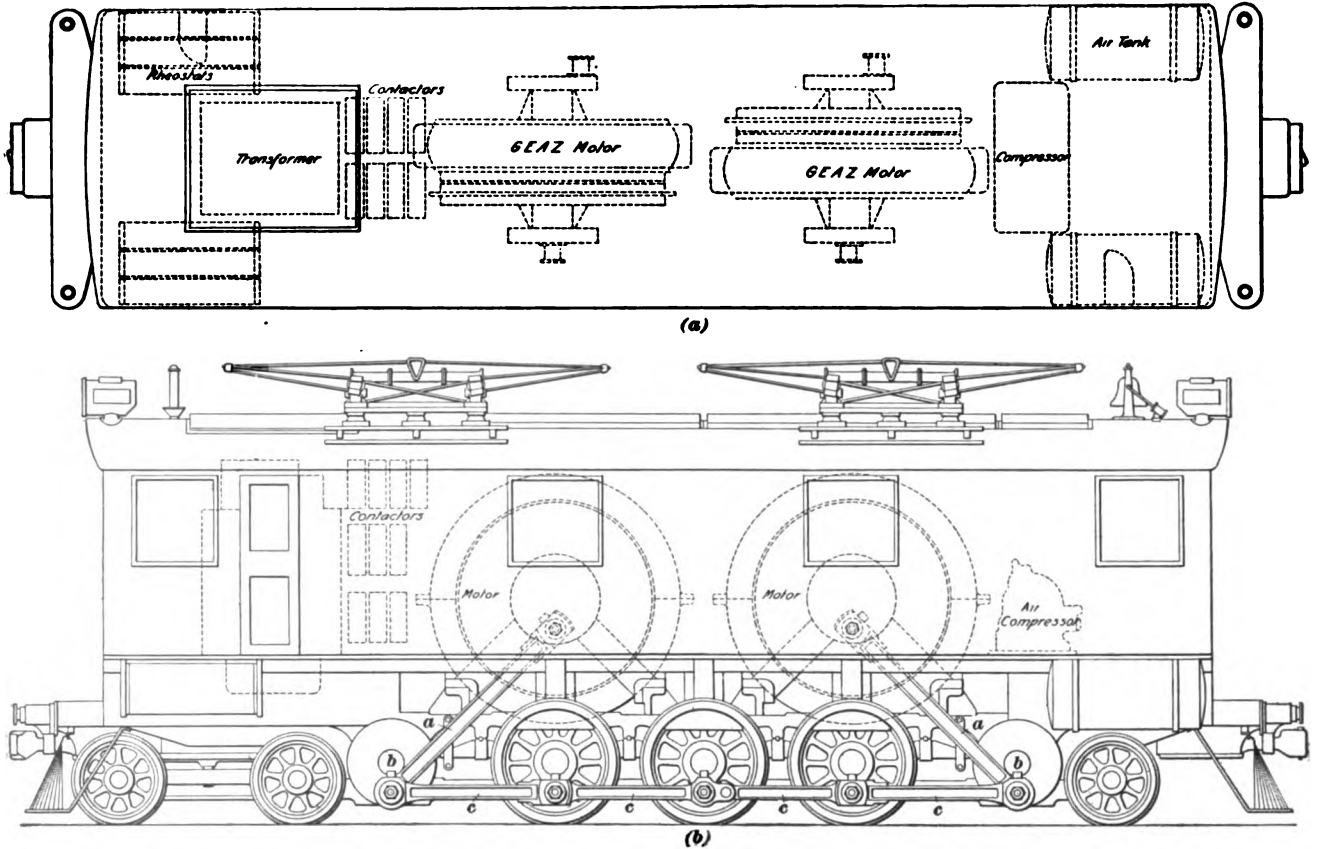

FIG. 49

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cab. The center of gravity of the locomotive is higher than in the older type of electric locomotive, and this tends to decrease the lateral pressure on the rails and thus the wear on the wheel flanges and rail head.

In the type of side-rod locomotive shown in the figure, inclined connecting-rods *a*, on both sides of the motors, extend from the motor crank-pins to the crank-pins on the jack-shafts *b*. The jack-shafts and the driving wheels are connected by means of side rods *c* that are also installed on both sides of the locomotive.

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OPERATING INSTRUCTIONS

INTRODUCTION

1. In all car or train operation it is necessary to start or stop with as nearly a uniform change in motion as is possible. To do this with electric locomotives or cars, some form of control system is used that in a general way may be defined as a collection of apparatus the purpose of which is to raise or lower the line voltage uniformly for application to the motor terminals.

Owing to the many different types of successful control systems and their wide range of application, it is necessary to take up each type independently. In order that a proper understanding may be obtained of the correct working of the control apparatus, the descriptions of the detail parts of the apparatus given in *Electric Locomotives* should have careful attention and study. The success of the motorman in operating the apparatus and locating faults depends on his familiarity with each unit part of the control system.

2. Since the advent of a single-phase railway motor, the control systems may conveniently be divided into three classes: (1) Single-phase alternating-current control; (2) direct-current control; (3) both alternating-current and direct-current control.

The voltage applied to the terminals of the motor may be regulated, in the first class, by means of a combination of bridging transformer taps, resistances, and series-parallel connection of the motors; in the second class, by means of a combination of resistances and series-parallel connection of

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the motors; and in the third class, by means of a combination of the first two methods.

Instructions governing the operation of the control systems of certain types of locomotives and the multiple-unit trains follow, but many of these instructions may be taken to apply in general to all classes of electric-control systems.

ST. CLAIR TUNNEL LOCOMOTIVE

INSPECTION AND PREPARATION FOR A RUN

3. Preliminary Inspection.—The motorman, on taking charge of the locomotive in preparation for a run, should first make a careful examination of the locomotive from the outside. The condition of all bearings, both on the motors and on the axles, should be carefully noted. See that all of the air-hose connections are properly made and that the safety chain is removed from the trolley.

On entering the locomotive, the following conditions should be found to exist: (1) Blower switch *15*, Fig. 1, and compressor switch *16* in the off-position; (2) battery switches *24* and *25* open; (3) heater switches *14* open; (4) master-control lever in the off-position, with reverse lever and plug removed. The operator should remove the reverse lever and plug when leaving the locomotive even temporarily.

4. Preparation for a Run.—The following operations should be made in the order indicated by the numbers:

1. Insert plug and reverse lever in controller.
2. Close the battery switches *24* and *25* up or down on alternate days; the rule usually observed is up on even days and down on odd days of the month.
3. Raise the trolley by pressing the trolley unlock button on the controller; if there is sufficient air pressure in the main reservoir, the trolley will rise. If it does not rise, turn the three-way cock *51* on the emergency reservoir 90° to the right, then press the unlock button and the trolley will rise,

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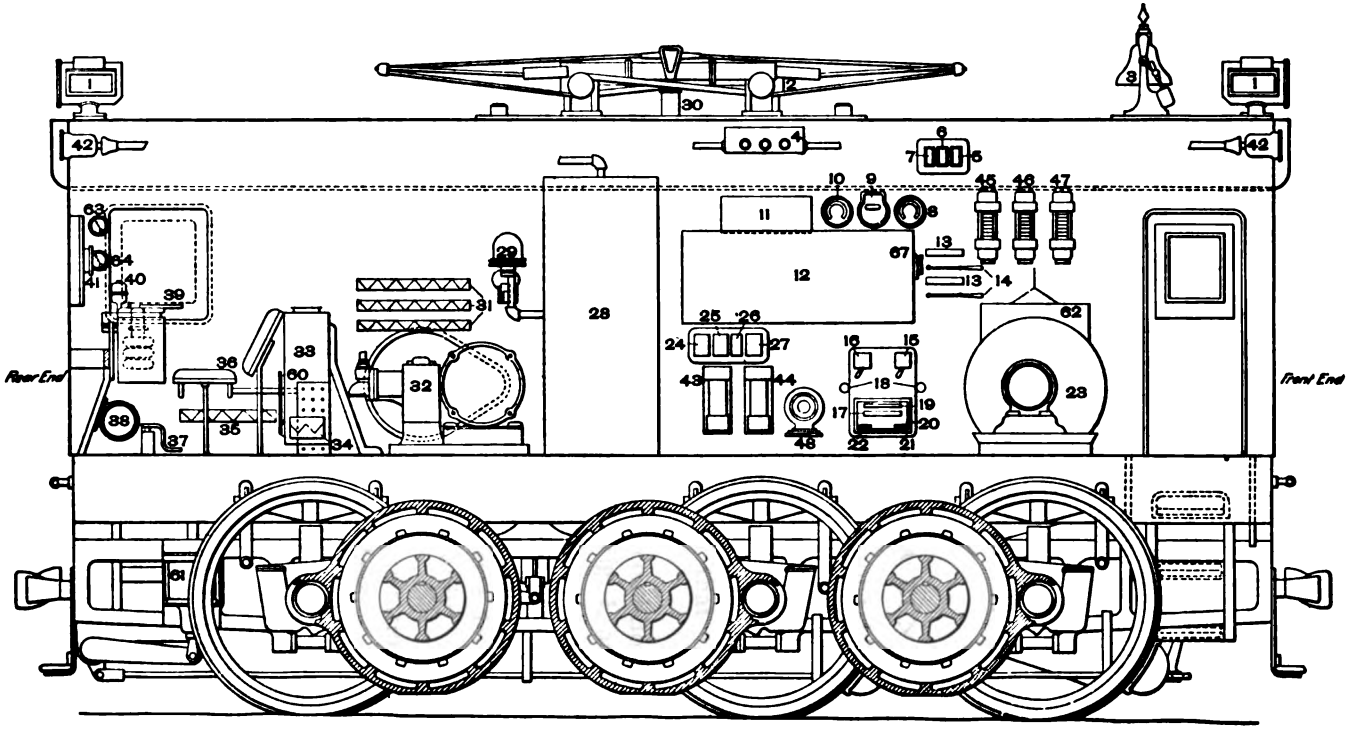

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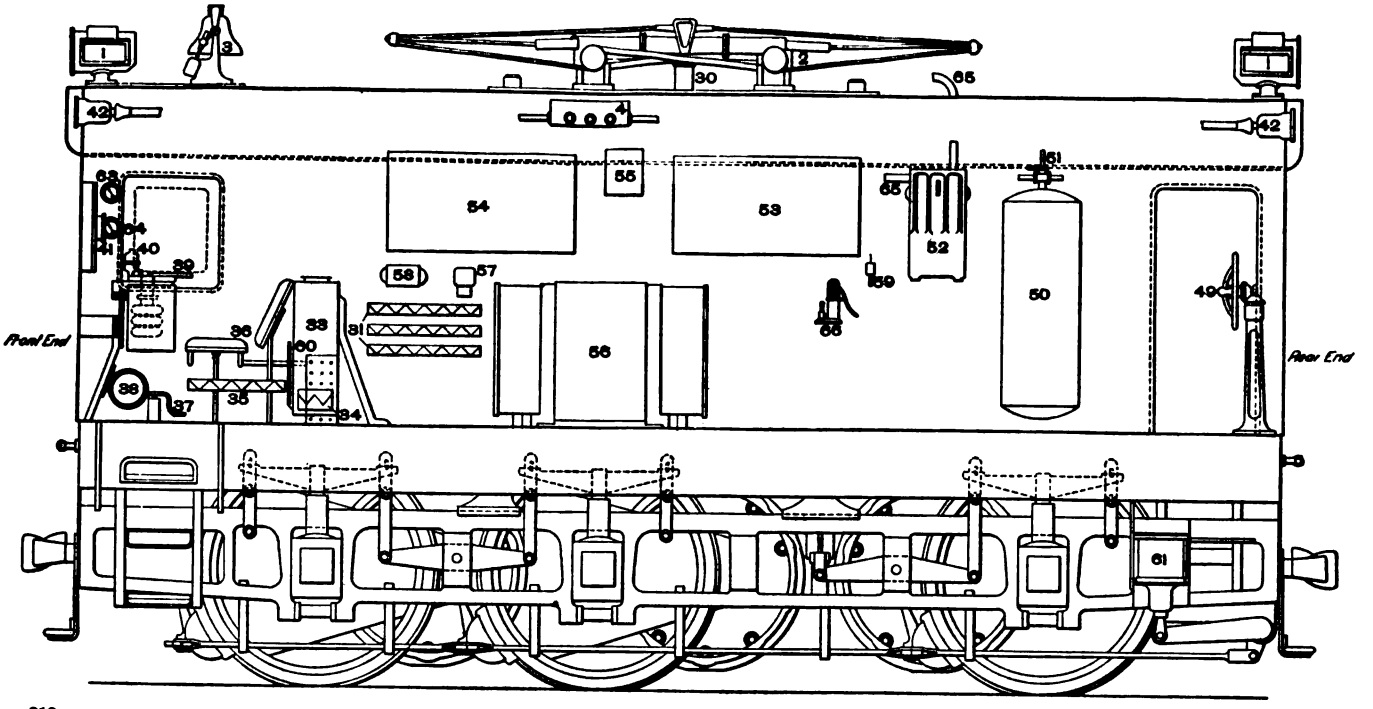

FIG. 1

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provided there is air pressure in this reservoir. If not, it will be necessary to use the hand pump *66* as explained later.

4. Push the line-switch reset button on the controller, which will cause the line switch to close, provided there is sufficient pressure in the reservoir.

5. If there is not sufficient air pressure, close the air-compressor switch *16* and then pull the line switch by hand into its closed position, holding it closed until sufficient air pressure is set up in the air reservoir by the air compressor to hold the switch in its closed position.

6. Start the motor generator set by closing switch *27 first* and then switch *26*.

7. Start the blower motor; this motor is kept in continuous operation while the locomotive is running.

8. See that the air pressure is normal and test out the brakes by setting and releasing them, noting the condition of the brakes from the outside of the cab after each test, or by signal from the other train operators.

9. See that the sand boxes are full and that the sand is perfectly dry. If necessary, close switches *18*, thus energizing the sand heaters.

10. Test out lights, signal bell, and whistle.

If the multiple operation of two or more locomotives is required, the following additional points should be observed:

11. See that the train line is properly made up by means of the three jumper connections being placed in their proper sockets, noting that the outside jumpers should be crossed between locomotives.

12. Remove all reverse levers and control plugs from the controllers in all the locomotives except the one from which the train is to be operated.

13. Close all the switches, see that all the trolleys are up, and test out the air in the same manner as for a single locomotive.

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STARTING AND OPERATION

5. The master controller for the St. Clair tunnel locomotive has twenty notches in the control circuit, of which seventeen are running notches and three are accelerating, or switching, notches. These three notches are Nos. 1, 2, and 3, and they should never be used except for intermittent work, such as switching, making up trains, or other service where low speeds are desired. The remaining notches, Nos. 4 to 20, inclusive, are running notches, and the controller can remain on any one of these notches for continuous operation, according to the speeds desired.

Everything being in readiness to start, the reverse lever is thrown in the proper direction, and the control lever notched up to give a uniform start. When bringing the controller forward, careful note should be made of the readings of the ammeter in order to make sure that only a reasonable starting current is taken, and to thus avoid operating the circuit-breakers. Under normal operating conditions, 4,580 amperes should not be exceeded. If this current is exceeded, the circuit-breakers will open, since they are set for this amount. By noting the position of the ammeter needle, it is possible, after a little experience, to obtain a very uniform acceleration, the controller handle being brought forward notch by notch as the current indicated by the ammeter tends to drop off.

TRAIN FAILURE

6. If the first movement of the train or the preliminary starting of the auxiliary apparatus should be accompanied by any unusual sounds, the odors of burning insulation or oil, the blowing of fuses, short circuits, open circuits, or by any conditions out of the ordinary, the controller should be immediately thrown to the off-position, the trolley forced down by pressing the controller button marked "Trolley Down," and an investigation made.

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If the train fails to move or any of these troubles are experienced, the fault may be due to disorder in any one or more of the following pieces of apparatus: Batteries; trolleys; transformers; circuit-breakers; switch groups; train-line relay; master controller; main motors; fuses; failure of air in either the air compressor or the blower; sanders; lights.

7. Batteries.—Battery troubles in connection with the control circuit are nearly always caused by a low charge. If such is the case, the discharged set of batteries should be cut out of circuit and the other set cut into circuit by reversing the position of battery switches *24* and *25*, Fig. 1. Broken connections, broken battery plates, etc. can be tested for and located by means of the 20-volt lamp that is provided and by close inspection.

8. Trolleys.—The trolleys should be inspected each day and proper lubrication provided by means of graphite placed in a central groove in the bows.

After the locomotive has been standing for some time, the main-reservoir pressure, normally 110 pounds, may become so low that it is impossible to raise or lower the trolley. The next step is to use the auxiliary reservoir by the method previously described. If this pressure is also too low to operate the valve, it is necessary to use the hand pump. This may be done by closing the cock in the air pipe connecting the auxiliary magnet valve to the trolley-unlock cylinder and opening the cock connecting this cylinder to the hand pump; then a few strokes of the pump handle will give sufficient air pressure to release the trolley and cause it to raise automatically. After the trolley is raised, close the connection to the hand pump and open the valve connecting the auxiliary magnet valve to the unlock cylinder.

All automatic operations failing, it is possible to raise the trolley by use of the wooden pole, on one end of which is provided a hook. By means of this hook pull out the latch in the trolley lock. The trolley can also be lowered by means of the pole.

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Never go on the roof of a locomotive while the trolley is up.

In case it becomes necessary to go on the roof to examine the trolley, make sure that the trolley is down, and before making the inspection see that the trolley is locked by the safety chain, thereby grounding it.

9. Transformer.—In case of trouble in the transformer, cut the transformer out of circuit by means of the circuit-breaker, or line switch, *52*, Fig. 1. Make an examination in order to determine whether or not the trouble is in the winding. The fault may be due to either a short circuit or a ground; in either case, nothing can be done while on the road.

10. Circuit-Breaker, or Line Switch.—The failure of the line switch to stay in may be due to one or more of the following causes: Excessive current; low voltage; insufficient holding tension in the spring; short circuit; grounds in any part of the main circuits.

Under normal conditions, the line switch can be reset by means of the reset button on the controller when the controller is in the off-position only. The line switch may also be reset by hand.

The line switch can be opened for testing and inspection purposes by dropping the trolley for an instant, by opening the battery switches, or by taking out the plug in the side of the controller.

By noting the reading of the ammeter during acceleration or when the locomotive is pulling a heavy load, it is possible to avoid tripping the breaker by excessive current. A maximum value of 4,580 amperes should not be exceeded in normal operation. If this current is exceeded, the overload relay *57*, Fig. 1, for the circuit-breaker opens the battery circuit to the magnet valve of the circuit-breaker and thus causes the breaker to open.

When the circuit-breaker is normally closed, a voltage relay establishes a holding circuit that keeps the breaker

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in its closed position as long as there is voltage on the line. Should the voltage drop to a very low value, or go off the line entirely, this relay loses its holding power and the breaker opens. The breaker cannot be reset by means of the reset button nor can it be permanently closed by hand until the voltage is about normal.

If the breaker opens repeatedly before the ammeter indicates the maximum allowable current through the motors, the adjusting screw on the overload relay *57* should be adjusted to a point that will allow the maximum allowable current to pass before the trip operates.

If, when notching up the control, the breaker goes out without apparent cause, the main motors should be cut out one at a time by means of the cut-out switches *67* on the end of the No. 260 switch group *12*. If the cutting out of one motor eliminates the trouble, the train can be run to its destination by means of the two remaining motors. If the cutting out of the main motors does not remove the difficulty, the main wiring should be examined for grounds or short circuits by means of the battery circuit and test lamp or by means of a magneto.

11. Switch Groups.—A failure of the unit-switch groups can often be traced to one or more of the following causes: Low air pressure; low battery voltage; loose contacts in the control circuits.

If the main-reservoir pressure is above 80 pounds, but there is low air pressure on the switch group, the three-way cock *51*, Fig. 1, or the reducing valve that feeds the reservoir should be examined carefully for obstructions. The three-way cock can usually be cleared by throwing the handle rapidly from one extreme to the other, then returning it to the normal position. A failure of the reducing valve to operate properly can often be eliminated by tapping the valve sharply several times with a hammer.

If, upon the movement of the master-controller handle, a sluggish operation of the unit switches ensues, or if one or more of the switches fail to close in their proper sequence,

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the indication is that the battery set that is in use has been exhausted, and the other battery set should then be cut in by throwing switches *24* and *25*.

If the trouble is not due to low air pressure or low voltage, it may be due to poor contact of some of the fingers of the train-line relay *55*, of the master controller *39*, or of the unit-switch interlocks. To test for the finger or fingers that may be making poor contact, lower the trolley and lock it with the safety chain. Remove the enclosing cases from the train-line relay and the controller, in order to facilitate a complete inspection. With the circuit-breaker closed, pull the control lever forward slowly notch by notch until a failure is noted. Leaving the control handle in this position, take a small piece of wood and brush along the fingers in the train-line relay, in the controller, and in the unit-switch interlocks. Failure of the fingers to make proper contact may be noted because of the motion imparted to the faulty fingers, and the necessary adjustment of the fingers giving trouble can then be made.

12. Train-Line Relay.—A failure of the train-line relay to operate after the control handle has passed the twelfth notch, either when notching up or when throwing off, may be due to a loose connection or to the sticking of the magnet valve of the relay.

13. Master Controller.—If the master-controller casing is removed, any mechanical disarrangement of the fingers or of the contacts can usually be noted. For poor contacts that are not noticeable by sight, the test previously described for trouble in the unit-switch interlock fingers may be applied. Notch up until failure occurs, then brush the contact fingers lightly with a piece of wood until the faulty fingers are located. In case of any serious disarrangement of the parts, burn-outs, or any difficulty not easily remedied on the road, the defective controller should be cut out, the reverse lever and plug removed, and the locomotive operated from the other controller.

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The control handle and the reverse lever are interlocked in such a manner that it is impossible to throw the reverse lever without first returning the control handle to the off-position.

If the brakes should fail to work, or in case of an emergency, the motors may be used for braking in the following manner: Throw the control lever to the off-position; throw the reverse lever to the opposite position from its original position and notch up the controller slowly until the stop is made. Care should be taken not to notch up too rapidly, for in such case the circuit-breaker will open. If this should happen, an emergency stop could still be made, but not so smoothly. When the circuit-breaker is off, the reverse lever thrown to the opposite position from its original position, and the control handle moved to on-position, the motors will act as generators and force direct current through the transformer to the ground, thus braking the locomotive. If the brakes are out of order, the circuit-breaker open, and the car is running backwards down the hill, leave the reverse handle at forward position and advance the control handle to the on-position in order to use the motors as brakes.

14. Main Motors.—In case of troubles with the main motors, an examination should first be made of the bearings; if running hot, they should be cooled, repacked with waste, and flooded with oil.

If the troubles are electrical in nature, they will most probably be a ground, an open circuit, or a short circuit in the armature winding or in the stationary field winding. A ground or short circuit in the armature winding or an open circuit in the stationary field winding cannot be repaired on the road, and the defective motor should be cut out. The effect of an open-circuited armature coil can be recognized at once by the vicious sparking at the brushes that occurs at regular intervals as the defective coil is commutated. A motor will stand this for a short time, but serious pitting of the commutator occurs. If it becomes badly pitted serious sparking ensues, and the life of the commutator is shortened.

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When trying to locate motor troubles, careful attention should be given to the brushes, shunts, and brush holders. See that the fingers have sufficient tension and that all chipped or broken brushes are replaced.

15. Fuses.—In case of trouble with any piece of apparatus, one of the first places to look for the cause is in the fuses. To determine whether a fuse has blown, first inspect the telltale circle on the side of the fuse; if this is charred, the fuse is burned out and should be replaced by a new one. These telltale tests are not always reliable, and in case of doubt test out the fuse by means of the testing lamp.

The following fuses are in the locomotive and should be inspected in case of trouble: Blower fuse *17*; compressor fuse *19*; sand-heater fuse *21*; cab-heater fuse *13*; light-switch fuses *5*, *6*, and *7*. Any of the fuses may be replaced safely by first opening the switch controlling the disordered piece of apparatus.

16. Air Compressor.—One of the most important pieces of auxiliary apparatus in the locomotive is the air compressor *32*, Fig. 1. A failure of the air compressor affects not only the braking system, but also the control system and such devices as the bell, the sanders, the whistle, and the trolley lock and unlock.

The emergency reservoir does not have sufficient capacity to be of service in connection with the braking system. The capacity of the emergency reservoir is only sufficient for about ten or twelve applications of the controller.

Particular attention should be given to lubrication of the compressor set, especially in the cylinder and reciprocating parts. In case of pounding or knocking, an examination should be made of the piston clearances at the heads of the pistons and of the crank and connecting-rod parts for loose brasses. The instructions given with reference to the main motors apply to the compressor motor.

17. Blower.—The transformers and motors depend for their continuous operation on the circulating air set up

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by the blower set *23*. Without the aid of the blower set, the operation of the locomotive under heavy loads could be continued but for a comparatively short time, and there would be excessive heating, thus endangering the apparatus. There is very little probability of encountering trouble in the fan except from foreign substances that might get into the fan or from hot bearings.

The instructions given with reference to the main motors apply to the blower motor.

18. Sanders.—The sanders located at each end of the locomotive are governed pneumatically. A current of air carries the sand to the track, the air being controlled by an electromagnet valve operated by a push button on the master controller, or by a foot-pedal *37*, Fig. 1. The sanders are also provided with hand levers *60* for emergency use. Sand-box heaters *34* are also provided; these should be used only long enough to thoroughly dry out the sand.

19. Lights.—The locomotives are provided with three separate light circuits, each circuit having fused switches *5*, *6*, and *7*, Fig. 1. Switch *5* controls the circuit to the headlight, meter, and gauge light at the front end of the locomotive. Switch *7* controls the circuit to similar devices at the rear end of the locomotive. Switch *6* is used for the lights dotting the ceiling of the cab. During locomotive operation at night, the rear and ceiling lights should be dark. The No. *5* switch circuit is alone used. It is necessary to keep the cab as dark as possible to enable the motorman to see the track ahead.

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NEW YORK, NEW HAVEN, AND HARTFORD LOCOMOTIVE

INSPECTION AND PREPARATION FOR A RUN

DIRECT-CURRENT ZONE

20. Inspection.—When taking charge of a locomotive, the motorman should make the usual outside examination of the locomotive as to bearings and lubrication, and see that all the necessary air connections are properly made.

With the locomotive standing in the direct-current zone, the following conditions should exist: (1) Both trolleys *18* and *57*, Fig. 2, locked down; (2) both handles of alternating-current circuit-breaker *143* open; (3) both air-compressor switches *71* and *128* open; (4) both blower switches *70* and *127* open; (5) controller lever in the off-position with reverse lever and controller plug removed; (6) battery switches *167* and *168* and motor-generator switches *169* and *170* open; (7) change-over switch in direct-current position; (8) third-rail shoes up; (9) direct-current main switch *61* open (down against wooden peg); (10) double-throw heater switches *114* and *181* in down position; (11) train-line heater switch *115* open; (12) hand brake *39* set.

21. Preparation.—The following operations should be made in the order indicated by the numbers when the locomotive is to be operated in the direct-current zone:

1. Lower the third-rail shoes by pressing the button in the master controller marked "Shoes Down."

2. Start the air compressors *66* and *123*, Fig. 2, noting that 130 pounds air pressure is obtained and that the com-

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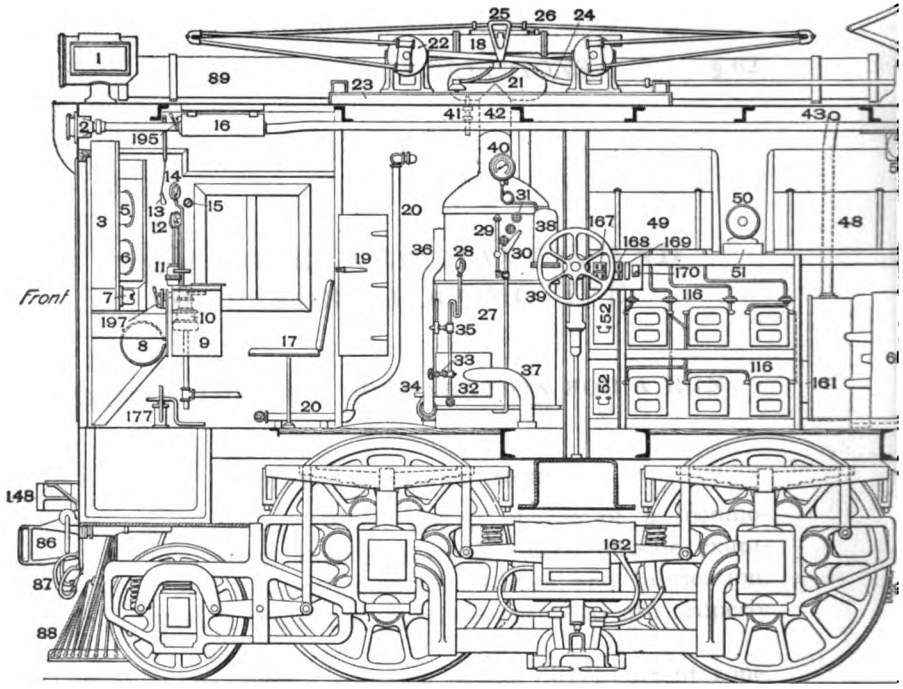

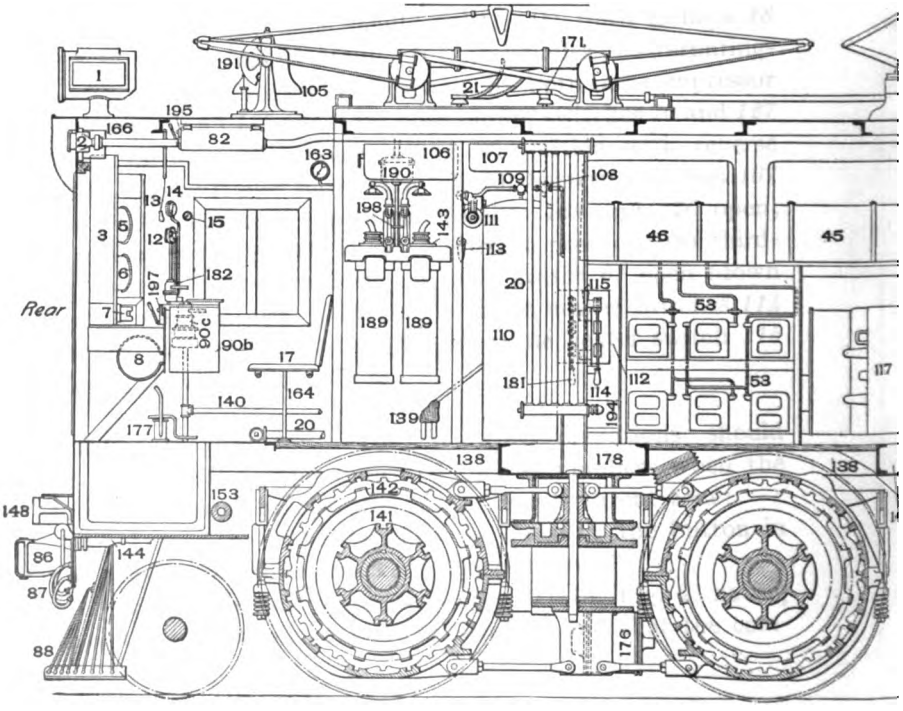

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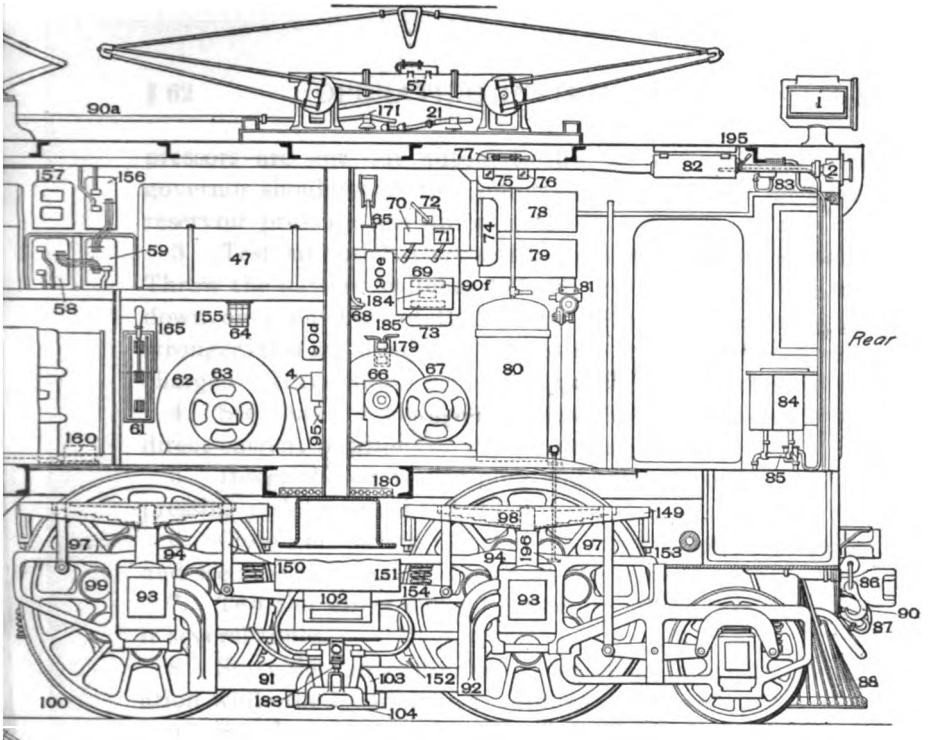

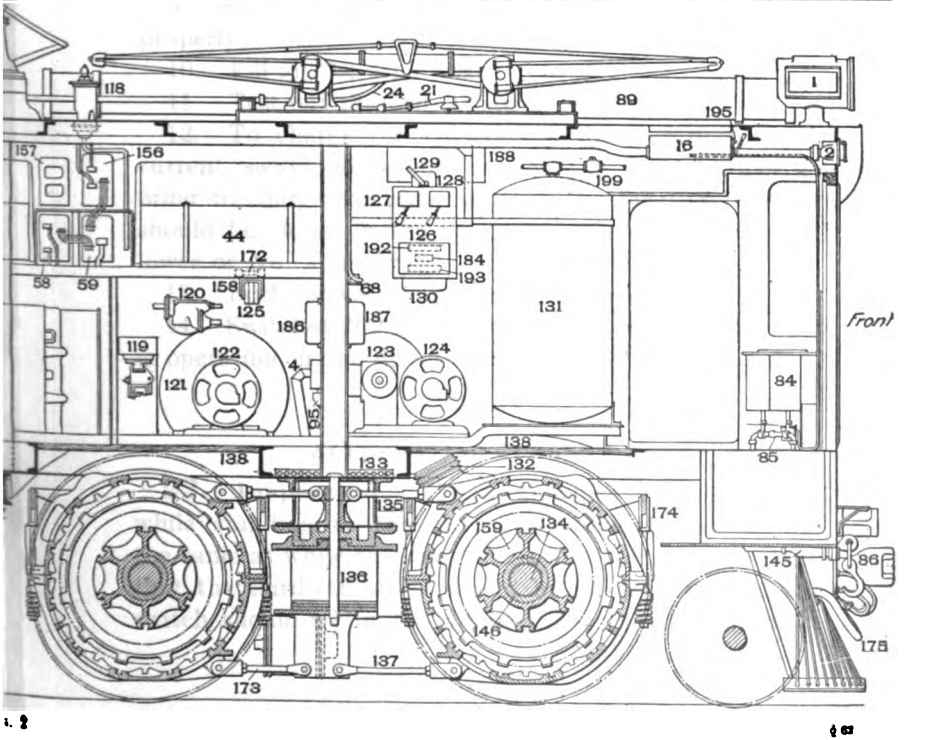

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pressors are cut out automatically at this pressure. The governor should start the compressors again after the main-reservoir pressure has dropped to 120 pounds.

3. Test out both battery sets by means of the 20-volt lamp. Throw the battery switches *167* and *168* up on odd days and down on even days of the month. If one set tests out the stronger, this set should be used while the weak one is being charged. Have motor-generator switches *169* and *170* open.

4. See that the change-over switches are thrown to the direct-current position, or with handles up.

5. Insert the controller plug and test out its contact by pressing pedal marked "Bell."

6. Close the switch *197* on the front master controller and see that this switch is open on the remaining controllers.

7. Test the direct-current trolley by raising and lowering it several times.

8. Start the fan motors and keep them in constant operation while the locomotive is running.

9. See that the brake valves and the brakes are operating properly.

10. Fill all the sand boxes.

11. Test out the bell, sanders, and lights.

12. To charge the batteries while operating on direct-current, switch *167* should be closed in the down position in order to charge the upper or No. 1 battery; and switch *168* should be closed in the up position in order to charge the lower or No. 2 battery.

13. Both blower motors should be started.

14. Switches *169* and *170* are open while the locomotive is operating in the direct-current zone.

ALTERNATING-CURRENT ZONE

22. Inspection.—The arrangement of the apparatus while standing in the alternating-current zone should be the same as while standing in the direct-current zone, except that the third-rail shoes should be up and the change-over switch should be in the alternating-current position.

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23. Preparation.—The following operations should be made in the order indicated by the numbers when the locomotive is to be operated in the alternating-current zone:

1. Have both handles of alternating-current circuit-breaker *143*, Fig. 2, at open positions, and both trolley safety-chain catches unhooked.

2. Test out the batteries as previously described for starting on direct current.

3. Insert the controller plug.

4. Raise the alternating-current trolley by pressing the controller buttons marked "Alternating-Current Trolley Down" and "Shoe and Trolley Unlock," releasing the button marked "Alternating-Current Trolley Down" first. If there is not sufficient air pressure to unlock the trolley, No. 2 trolley can be raised by use of the hand pump *65*. But one trolley on each locomotive should be used while operating on alternating current, preferably the rear one.

5. Close both handles of the alternating-current circuit-breaker *143* and note that the transformers are energized.

6. Have the change-over switches in the alternating-current position with handles down.

7. Start the air compressors as explained for direct-current operation.

8. Start the fan motors as explained for direct-current operation.

9. Fill the sand boxes, test out brake valves and brakes, bell, sanders, and light circuits as explained for direct-current operation.

10. To charge the batteries while operating on alternating current, start the motor generator by closing the snap switch *170* and the knife switch *169*, care being taken to close the snap switch *170* first and to see that the motor generator starts properly. The battery switches *167* and *168* should be closed in positions according to the battery set to be charged, as explained for direct-current operation.

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OPERATION

FIRST MOVEMENT OF THE LOCOMOTIVE

24. If the first movement of the locomotive is attended by any irregularity, such as a short circuit, open circuit, arcing, blowing of a fuse, smoke, unusual noises, etc., the motorman should immediately throw the controller to the off-position. If operating with alternating current, press the controller button marked "Alternating-Current Trolley Down." If operating with direct current, and an arc has formed inside of the locomotive that does not clear itself at once, close switch *195*, which operates the short-circuiting switch *194*. The operation of the short-circuiting switch will cause the shoe fuses to blow at once. Insert paddles between the shoes and third rail and then investigate to determine the cause of the trouble.

DIRECT-CURRENT ZONE

25. For the operation of trains with direct current, there are four economical working positions for the controller: Direct-current series; direct-current shunt, No. 1; direct-current shunt, No. 2; direct-current full multiple.

The controller handle may be retained on any of these four notches, according to the speed desired. The other notches are uneconomical and the controller should never be retained on them except for the short period of time necessary for smooth acceleration. These secondary notches are combinations of grid resistances, and the grids are liable to overheating and burning.

When starting the train, the controller handle should be brought promptly from one running notch to the other, noting by the ammeter that 1,800 amperes is not exceeded. The highest speed is obtained when using the direct-current full-multiple position. Care should be taken not to exceed 1,200 amperes after full speed has been reached.

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If at any time during the starting or the switching operations of the train 2,500 amperes be exceeded, the direct-current circuit-breaker will open. To reset the breaker, the controller handle should be returned to the off-position, and the circuit-breaker reset button pushed. If this button should not operate properly, the breaker may be pulled into closed position by hand.

In case two locomotives are used, the notching up of the control should be done more slowly to give time for the taking up of the slack space between locomotives and between cars.

ALTERNATING-CURRENT ZONE

26. For the operation of trains with alternating current, there are six economical positions of the controller: Alternating current, No. 1; alternating current, No. 2; alternating current, No. 3; alternating current, No. 4; alternating current, No. 5; alternating current, No. 6.

The first notch of the controller, when using alternating current, is the alternating-current switching notch. This is the only notch on which the controller should not be retained for any extended length of time.

As in direct-current operation, careful note of the ammeter should be made to see that 1,600 to 1,800 amperes is not exceeded. The circuit-breaker will be thrown if the current exceeds 2,500 amperes.

If the controller handle should by mistake be carried beyond the sixth notch, the power will be cut off the locomotive. In such a case the handle should be immediately returned to the sixth notch. If the speed drops before this is done, remove the plug from the side of the controller and return the controller handle to the off-position. Again insert the plug and notch up the controller as usual in order to obtain the desired speed.

The locomotive should never be allowed to stand with current passing through the motors.

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TO CHANGE FROM DIRECT- TO ALTERNATING-CURRENT OPERATION

27. To change from direct-current to alternating-current operation, on reaching the sign post marked "Controller Off," open switch *197* on the back of the master controller and put in the alternating-current circuit-breaker. Then make the following operations:

1. Throw the controller to the off-position.
2. Press the button marked "Shoe and Trolley Unlock," and hold this button down until the third-rail shoes have folded up to the side of the locomotive and the alternating-current trolleys are unlocked and have been raised.
3. When the trolleys make contact with the overhead wire, close the motor-generator switches *170* and *169*; be careful to close switch *170* first and note that the motor generator starts up before closing switch *169*.
4. Open the main direct-current knife switch. When the third-rail shoes are closed in their upper position and the alternating-current trolley is in contact with the overhead wire, alternating current enters the locomotive and all the direct-current apparatus is automatically cut out and the alternating-current apparatus is cut in. As soon as the operations have taken place in their proper order, the transformers are energized and the controller can be notched up to give the desired speed.
5. The reading of the ammeter should be noted to determine whether or not the motors are working properly.

TO CHANGE FROM ALTERNATING- TO DIRECT-CURRENT OPERATION

28. The sign posts marked "Shoes Down" and "Power Off" give notice that the apparatus should be changed from the connections suitable for alternating-current operation to the connections suitable for direct-current operation.

To cause the shoes to make contact with the third rail, press the controller button marked "Shoes Down," and see

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that the shoes on both sides of the locomotive go down. When the third-rail shoes are lowered, they are automatically locked in position. If any of the shoes fail to lower, they should be forced down by hand. Then make the following operations:

1. Close the main direct-current switch.
2. Open the storage-battery knife switch *169* and then the motor-generator snap switch *170*.
3. After reaching the second sign post marked "Power Off," throw the controller handle to the off-position.
4. Close the small switch *197* on the back of the controller. This action causes the alternating-current trolleys to lower and the change-over switches to be thrown to their direct-current positions. If the trolleys do not come down automatically, they should be pulled down by means of the wooden pole and hook.
5. Open both handles of the alternating-current circuit-breaker *143*.

These operations having taken place in their proper sequence, direct current enters the locomotive and the controller can be notched up to give the desired speed.

MULTIPLE OPERATION OF LOCOMOTIVES

29. When two or more locomotives are to be operated in multiple, they must be operated from the controller in one locomotive, preferably from the forward end of the leading locomotive. The following operations should then be made:

1. Make the jumper connections between all the locomotives by means of the cables provided for this purpose.
2. Test out the controller on each locomotive to insure its correct operation.
3. Remove the controller handles and plugs from all the controllers except the one from which the train is to be operated.

When operating with alternating current, one trolley from each locomotive should be used, preferably the rear one. In

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case of trouble, if the small switch on the back of any controller is closed, the alternating-current trolleys will be pulled down, regardless of the plugs on some of the controllers being out.

RAISING THE TROLLEYS

30. Direct-Current Trolley.—To raise the direct-current trolley for use over gaps in the third rails, hold down the controller button marked "Direct-Current Trolley Up," and operate the controller handle in the same manner as for direct-current service on the third rail.

In order to keep the direct-current trolley in contact with the overhead wire or rail, it is necessary to retain pressure on the button marked "Direct-Current Trolley Up," until the shoes again reach the third-rail section. Care should be taken that the controller is either returned to the off-position before the direct-current trolley is lowered, or that the direct-current trolley remains up until the third-rail shoes have reached the third-rail section.

31. Alternating-Current Trolley.—To raise the alternating-current trolley under normal conditions, first press down the button marked "Alternating-Current Trolley Down," release this button, and then press down the button marked "Shoe and Trolley Unlock." After the air pressure in the trolley cylinder has had time to take up the pressure of the trolley springs, the trolley unlock should be operated and the trolley will rise.

After the locomotive has been standing for some time, the air pressure of the reservoir may become too low to operate the trolley valves; in this case, No. 2 trolley can be unlocked by means of the hand pumps *65*, Fig. 2. This operation can be performed by closing the cock in the air pipe connecting the trolley to its magnet valve, then opening the cock connecting the trolley lock to the hand pump, and giving the pump three or four strokes. After the trolley has been raised, these connections to the hand pump should be reversed, so

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that the trolley can be operated automatically after the air pressure is normal.

Failing to raise the trolley by these methods, the trolley lock may be opened by means of the pole and hook carried on the locomotive.

Never go on top of the locomotive for this operation.

TESTING THE CONTROL APPARATUS

32. Direct Current.—To test the direct-current control apparatus while the locomotive is in the direct-current zone, the third-rail shoes being in contact with the third rail, the following operations should be performed: (1) Open the direct-current main switch *61*, Fig. 2; (2) insert the reverse lever in the controller and move it to the forward position; (3) bring the master-controller handle to the direct-current switching position, and notch it up for each successive notch until the direct-current full-multiple position is reached. Take careful note that the switches close in their proper sequence at each of these notches; (4) return the controller handle to the off-position; (5) throw the reverse lever to the backward position and repeat the test; (6) repeat all of these tests, using the other master controller in the locomotive; (7) close the direct-current main switch *61* in the upward position.

It should be observed that opening the main switch *61* to perform these tests does not cut off current from the lighting, heating, compressor, or blower circuits.

To further test the controller apparatus, but while the locomotive is standing in the alternating-current zone, the following operations should be performed: (1) Open both handles of the alternating-current circuit-breaker *143*; (2) close the small switch *197*, Fig. 2, on the back of the controller; this lowers the alternating-current trolley, forces down the third-rail shoes, and all change-over switches take the direct-current position; (3) make the test for correct operation and proper sequence of switches as previously described; (4) open small switch *197*; (5) raise the alternating-

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current trolleys and the third-rail shoes; (6) close the alternating-current circuit-breaker handles, and all change-over switches will then take the alternating-current position.

33. Alternating Current.—To test the alternating-current control apparatus, the following operations should be performed: (1) Open both handles of the alternating-current circuit-breaker *143*, Fig. 2; (2) insert the reverse lever of the controller and bring the lever to the forward position; (3) notch up the controller to each successive alternating-current position, and note that the proper switches come in at each successive alternating-current position; (4) return the controller handle to the off-position; (5) throw the reverse lever to the backward position, and repeat the notching test; (6) the notching test should be repeated, using the other controller. It should be noted that the sequence of switches for the No. 2 master controller, forward direction, will be the same as for the No. 1 master controller in the reverse direction, and the sequence of switches for the No. 1 master controller, forward position, will be the same as for the No. 2 master controller in the reverse direction; (7) close both handles of the alternating-current circuit-breaker *143*.

MOTORS AS BRAKES

34. Reversing.—If the brakes should fail to operate properly, the motors can be used for braking in the following manner: (1) Place the controller handle in the off-position; (2) throw the reverse lever to the opposite position from that in which the controller has been operated; (3) notch up the controller slowly, until a stop is made, being very careful not to throw too much current on the motors, as this would result in an entire loss of power and possibly damage to the apparatus.

35. Generator Action of the Motors.—When the brakes fail and the power is off the line, the generator action of the motors may be employed for braking purposes as fol-

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lows: (1) Throw the reverse lever to the opposite position from its regular position corresponding to the existing direction of motion of the locomotive—that is, if the locomotive is moving forward, throw the reverse lever to the reverse position, but if the locomotive is rolling backwards down a grade, throw the reverse lever to the forward position; (2) if the apparatus is connected for direct-current operation, move the controller handle to some point beyond the direct-current shunt No. 2 position; (3) if the apparatus is connected for alternating-current operation, move the lever to any of the alternating-current positions.

ELECTRIC HEATERS

36. The cars are electrically heated by either direct or alternating current. The current at a potential of 600 volts passes to the heater bus-line through the heater change-over switch *106*, Fig. 2. The bus-line may be connected throughout the train by means of jumper sockets *144* and *145*, provided beneath the floor at either end of the locomotive. A single-pole single-throw heater switch *115* connects the change-over switch *106* to the bus-line. In order to get either alternating current or direct current on the heater bus-line, this switch *115* must be closed. When the heaters are not in use, switch *115* should be opened. Alternating current flows to the change-over switch through a small transformer *112* which may be connected to either one or both of the main transformers. This connection may be made to No. 1 transformer through the single-pole double-throw knife switch *114*, and to the No. 2 transformer through switch *181*. Under normal conditions when current is taken from both transformers, both of these switches *114* and *181* should be in the upward position. If the heaters are not required, the switches should be in the downward position.

When No. 1 transformer is out of service, current can be supplied to the heater circuit by closing switch *114* down and switch *181* up. If No. 2 transformer is out of service, close switch *114* up and switch *181* down. When operating on

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direct current, switches *114* and *181* have no connections to make, since the change-over switch has direct connections to the third-rail shoes. When changing from alternating current to direct current or from direct current to alternating current, the change-over switch will automatically adjust the heater circuits.

BLOWERS AND COMPRESSORS

37. The two direct-connected motor-driven blower sets on each locomotive are operated on either alternating current or direct current. One or the other of these currents is automatically cut in or out by means of the change-over switches *73* and *130*. Each blower set is provided with a conduit *178* through which air passes to the transformer, motors, resistance grids, etc. The conduits from each blower set are connected in such a manner that, should one blower set become disabled, the remaining set can still be used to circulate air through the system, provided the two dampers in the conduit of the set not in use are closed. Closing these dampers prevents the active blower from exhausting through the conduit of the set not in operation. The air intake to the blower sets is fitted with shutters, which should be closed during stormy weather to prevent moisture being forced into the electric apparatus. Air will then be taken from the interior of the cab, in which case one of the cab doors or a trap door is usually opened to provide a sufficient supply of air.

The motors on both the blower and compressor sets should be cared for according to the directions already given for motor operation on the St. Clair tunnel locomotive.

SANDERS

38. In case of air leakage through one of the sanders, or any of its connections, cut off the sander air pipe by closing the cut-out cock provided for that purpose. If this is not done, the main-reservoir air pressure will be reduced or entirely lost.

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FUSES

39. Light Fuses.—The middle fuse *184*, Fig. 2, in fuse box *69* or in *126* is on the alternating-current lighting circuits. To replace these fuses, proceed as follows: (1) Open both handles of the alternating-current circuit-breaker *143*; (2) renew the fuse; (3) close both handles of the alternating-current circuit-breaker.

The fuses on the direct-current light circuit are combined with the fuses of the compressor motor while on direct current.

40. Heater Fuses.—The heater circuits are protected by a fuse located in the fuse box *107*; to replace this fuse while operating on alternating current, proceed as follows: (1) Open the three heater knife switches *114*, *115*, and *181*; (2) open both handles of the alternating-current circuit-breaker *143*; (3) replace the fuse; (4) close the switches *114*, *115*, and *181*; (5) close the alternating-current circuit-breaker.

To replace the heater fuse while operating on direct current, proceed as follows: (1) Open the single-throw heater switch *115*; (2) insert paddles between all the third-rail shoes and the third rail; (3) replace the fuse; (4) remove the paddles and close the heater-circuit switch *115*.

41. Blower and Compressor Fuses.—The top fuse *192* of the group of fuses near the No. 1 end is the direct-current blower fuse. The bottom fuses, *185* in one box and *193* in the other box, are the direct-current compressor fuses. To replace any of these fuses while operating on direct current, proceed as follows: (1) Open the direct-current main switch *61*; (2) insert paddles between all the third-rail shoes and the third rail; (3) replace the fuse; (4) remove all of the paddles, and close the direct-current main switch *61*.

For operation on alternating current, the upper fuse *90 f* in No. 2 fuse box is the No. 2 alternating-current compressor fuse. The left-hand fuse box *186* on the channel at No. 1 end contains the No. 1 alternating-current blower fuse. The right-hand fuse box *187* on the channel iron at the No. 1

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end contains the No. 1 alternating-current compressor fuse, and the fuse box *90 d* on the channel iron at the No. 2 end contains the No. 2 alternating-current blower fuse. To replace any of these fuses, proceed as follows: (1) Open both handles of the alternating-current circuit-breaker *143*; (2) replace the fuse; (3) close both handles of the alternating-current circuit-breaker.

42. Third-Rail Shoe Fuses.—To replace the third-rail shoe fuses, proceed as follows: (1) Open the direct-current main switch *61*; (2) open the compressor switches *71* and *128* and blower switches *70* and *127*; (3) open the knife switches *115* between the heater circuit and heater change-over switch; (4) insert the wooden paddles between all of the third-rail shoes and the third rail; (5) loosen up the thumbscrews at the end of the fuse box, remove the blown fuse, and insert the new one, being careful to secure good contact by tightening the thumbscrews. After replacing the fuses, remove all the wooden paddles, and again cut into circuit the apparatus previously cut out.

Care should be taken, when removing the paddles from beneath the shoes, to keep away from the front of the fuse box in case the fuses should blow again when the third-rail shoes make contact with the rail.

TRAIN FAILURE

43. Starting.—When starting a heavy train on a grade while operating on either alternating current or direct current, it may be necessary to use more than 1,800 amperes before the locomotive starts the train. In any case, 2,500 amperes should not be exceeded, as the circuit-breakers are set to open at this current.

When operating on alternating current and with one pair of motors cut out, if the locomotive does not start the train with the controller handle in the alternating-current No. 1 position, it can be moved to the alternating-current No. 2 position. If, however, the train does not start then, after

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all the train slack has been taken up, the train is too heavy for the locomotive.

When operating on direct current with one pair of motors cut out, a current of from 1,800 to 2,500 amperes can be used until the direct-current series position of the controller handle is reached.

In case of trouble with either of the transformers *60* or *117*, Fig. 2, when operating on alternating current, either one can be cut out by opening, by means of the handle, the circuit-breaker that feeds current to that transformer. Also make sure that the switch connecting that transformer to the balancing transformer is in the down position.

44. Alternating-Current Circuit-Breaker.—If, while operating on alternating current, a current of more than 2,500 amperes is taken by the motors, the circuit-breakers *143*, Fig. 2, will probably go out. The circuit-breakers can then be reset by hand.

If a circuit-breaker goes out repeatedly without apparent cause, and it is impossible to locate the difficulty, the control cut-out *72* or *129*, depending upon the side of the locomotive that the circuit-breaker controls, should be thrown to the off-position, which will cut out one pair of motors.

The control cut-out handle must always be in the off-position when an attempt is made to reset the circuit-breaker.

45. Alternating-Current Trolley.—In case of difficulty with either of the alternating-current trolleys *18* or *57*, lower the trolley by pressing the control button marked "Alternating-Current Trolley Down." Lock the trolley down if the locking mechanism is in working order, and close the air cock on the trolley side of the magnet valve leading to the unlocking cylinder of this trolley.

If the locking mechanism has been damaged, tie the trolley down with a rope, being careful that none of the metal parts of the trolley are in contact with the roof. Never use the safety chains in such case in place of the rope, because the safety chains are grounded.

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In case of trouble in the cable *90 a* that connects the two trolleys, disconnect the cable at the T near the No. 2 trolley base and draw the cable away from the base. The No. 1 trolley cannot now be used and must be kept down by either of the means just described.

In case either No. 1 or No. 2 trolley becomes grounded, disconnect the grounded trolley at a point near the base of the trolley main air cylinder.

46. Unit-Switch Group.—A failure of any one of the unit switch groups *44*, *45*, *46*, *47*, *48*, and *49*, Fig. 2, can often be traced to one of four reasons.

1. *Low Air Pressure.*—Look at the control-line pressure gauge *163* and note whether or not this gauge registers a pressure of at least 70 pounds. If a lower pressure than this is registered on the gauge with the normal pressure of 130 pounds on the main-reservoir gauge, look for the trouble in the three-way cock *109* or in the reducing valve *111*.

Any slight obstruction in the three-way cock can usually be removed by throwing the handle from one extreme position to the other several times, and then returning the handle to its normal central position.

Any slight obstruction in the reducing valve or its failure to work from any minor cause can be remedied by tapping it sharply several times with a hammer.

2. *Low Battery Voltage.*—If a movement of a handle of the master controller, with all of the apparatus in normal working condition, does not result in a movement of any of the multiple-unit switches, the probability is that the storage battery in service has been exhausted. In this event, throw storage-battery switches *167* and *168* to the reverse positions, which will cut in the other storage battery.

3. *Plug Making Poor Contact.*—The plug attached to the reverse lever may not be making proper contact.

4. *Poor Contacts in the Control Circuits.*—If a movement of the controller handle to the running positions results in the coming in of a portion of the switches and a failure on the part of others, the trouble is probably due to poor contacts

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of some of the fingers of the motor-control cut-outs *72* and *129*, the change-over switches *73* and *130*, the master controllers *9* and *90 b*, or the interlocks on switches in the switch groups. In such an event and if it is possible to handle the train with one pair of motors, cut out the side of the locomotive in which the failure occurs and operate with one pair of motors. If this cannot be done, arrange the locomotive circuits as described for testing the control apparatus and notch up the master controller until the point of failure is reached. Open the cover to the control cut-outs, change-over switches, and master controllers. Run a piece of wood along the control fingers and the interlocks. A failure to make contact can quickly be noted and an adjustment of the fingers giving the trouble can be made.

If the failure cannot be located in this way and remedied and it is impossible to handle the train with one pair of motors, call for assistance.

47. Third-Rail Shoe.—If a third-rail shoe, shoe support, or beam should be broken while running, the damaged part should be either broken entirely off or tied up, depending on which operation will be the safest and require the least amount of time. If operating in the alternating-current zone, the repair work can be done with impunity. If operating in the direct-current zone, before touching the shoes, open the direct-current main switch *61*, the compressor and blower switches *70*, *71*, *127*, and *128*, Fig. 2, the single-pole single-throw switch *115* connected to the heater change-over switch, and insert the wooden paddles between the third-rail shoes and the third rail. In knocking off the broken parts, use a tool with a wooden handle. **Never use a crowbar.**

For operation in the direct-current zone, it is necessary to have at least one good shoe on each side of each truck.

48. Change-Over Switch.—In case of trouble with the change-over switches *73* and *130*, Fig. 2, make the following examination: (1) See that the control line pressure gauge *163* registers a pressure of a least 70 pounds; (2) open relay box *74*

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and see that the relays are in their proper positions; that is, if operating on alternating current, both alternating-current relays should be up and the direct-current relay should be down; and if operating on direct current, both alternating-current relays should be down and the direct-current relay should be up. If the relays are not in their proper positions, do not attempt to make repairs on the road, but throw the change-over switch by hand and report the trouble to the proper official at the terminal. The lever for throwing this switch by hand is on the back end of the case close to the side of the cab. If operating on alternating current, throw the handle down. If operating on direct current, throw the handle up.

49. Master Controller.—A failure of the master controller may at times be caused by the displacement of one of the contact fingers. Such an occurrence can be readily noted by removing the cover of the controller and examining the fingers. Any slight difficulty of this nature can be remedied on the road, but in case of any serious disarrangement of the parts, the controller must be cut out, the reverse lever brought to its central position, the lever and the controller plug removed, and the locomotive operated with the controller at the other end.

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NEW YORK CENTRAL LOCOMOTIVE AND MULTIPLE-UNIT TRAIN

STARTING AND OPERATION

50. Preparations for a Start.—The usual preliminary examination should be made by passing along the outside of the train, carefully examining all bus-line and train-cable connections between cars, to see that they are properly made. Then pass along the inside of the train, closing all the third-rail and air-compressor switches, and opening the master-controller switches in all cars except the one from which the train is to be operated.

The operation in general is the same whether applied to locomotives or multiple-unit trains. The following discussion relates to this type of control in general. The details of some of the operations are different with some wiring installations than with others.

After the operator takes the position at the master controller from which the train is to be operated, which under normal conditions is in the forward end of the first car, all the circuit-breakers should be set by moving the circuit-breaker switch located over the master controller to the on-position, allowing sufficient time for all the breakers in the train to set. Also note the brake-pipe air pressure, which should be about 70 pounds. Make a thorough test of the air brakes, noting that they set and release with the proper air application.

51. Starting.—Press down the button in the controller handle, insert the handle key, and give it a quarter turn. It is necessary to keep the button in the handle depressed, to prevent the pilot valve in the controller from operating and applying the brakes. Move the handle to

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the left as far as it will go, keeping the button depressed and holding the handle against the spring, which tends to return it to the off-position. With the handle in its left-hand position, the control will notch up automatically, with the proper sequence of contactors and under the control of the current-limit relay, in case this relay is incorporated in the locomotive or multiple-unit car wiring. In some locomotives the relay is not used. The button must be held down in all but the off-position.

To start the train slowly by means of a controller having four notches, move the controller handle to the first notch; this connects both motors in series with resistance in circuit and the control will not notch up further.

If it is desired to increase the speed of the train slightly, without depending on the automatic action of the current-limit relay, move the controller handle to the second notch, but quickly return it to the first notch; each action results in cutting out one step of resistance, and the action can be repeated until all resistance steps are cut out. It will be noted that if the controller handle remains on the second notch too long the current-limit relay will act to automatically cut out the remaining resistance steps.

The second and fourth notches are the running positions, and for all continuous operation of the train these notches should be used. The control should remain on the intermediate notches but a few minutes at a time.

52. Coasting.—To shut off the power, the controller handle, with the button depressed, is moved to the off-position; the train will then coast freely.

53. Reversing.—To reverse the direction of train operation, move the control handle, with the button depressed, to the first notch on the right. In this position the motors will be connected in series with all resistance in circuit. On the second notch, the motors are in series without resistance in the circuit. For operation in the reverse direction, it is impossible to operate above half normal speed. If a

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higher speed is necessary than provided by the second reverse notch, it can be obtained by using the forward notches of the controller at the other end of the car or train.

54. Stops.—With the power removed, an application of the air brakes by means of the regular brake valve will give the usual service stop.

An automatic or an emergency stop may be made by relieving the button of pressure and by releasing the controller handle, which will then return to the off-position, shutting off the power and applying automatically the brakes.

An emergency stop, when the air brakes fail or for the prevention of an accident, can be made by moving the controller to the first notch in the reverse position.

TRAIN FAILURE

DEFECTS IN MASTER-CONTROL CIRCUIT

55. Open Circuit.—To test for an open circuit in the master-control circuit, move the master controller to the first notch and open the master-controller switch; a slight arcing indicates that the circuit was closed and that the trouble is somewhere else. No arcing at this switch indicates an open circuit and likely a blown fuse. If the fuses do not show a defect by the telltale device mounted on them, the fuses should be tested by placing them temporarily in the lighting circuit. Any defective fuses should be replaced.

56. Grounded Train Cable.—If the control-circuit fuse blows when the controller is operated, it is probable that one or more of the wires in the train cable are grounded. Disconnect the operating car from the rest of the train by disconnecting the train-cable jumpers. Replace the fuse, repeat the test, and if the new fuse blows, the trouble is in the operating car or its jumper. If the fuse does not blow, reconnect the adjacent car of the train, but disconnect the

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two cars from the rest of the train. Repeat the test and if the fuse blows, the difficulty is in the second car of the train or its jumper. This method of elimination should be repeated until the faulty car or jumper has been located. If the trouble is with a jumper, it should be replaced by a new one, or the one from the rear end of the last car of the train should be used.

If the fault is not found in a jumper it will be found in one of the cars of the train. Start in with the operating car and move the seven-point cut-out switch to the off-position and repeat the test; if the fuse does not blow, the trouble will be in the cut-out switch, in the contactors, in the reverser, or in the circuit-breaker. In this case the cut-out switch should remain in the off-position, thereby cutting this car out of service, but permitting, by means of the train cable, of the normal operation of all of the other cars in front or behind it.

57. If the opening of the cut-out switch does not remove the trouble, the difficulty then lies in the train cable of that car. It will then be necessary to disconnect this car entirely from the rest of the train. If the faulty car is near the rear of the train, operate from the front car as usual, but disconnect the disabled car, thereby disconnecting all the following cars. If near the front of the train, disconnect this car, thereby cutting out all forward cars, and operate the train from the first forward car that is not disconnected.

58. Master Controller.—If the contactors have a sluggish action or do not close in their proper sequence, the trouble is probably due to poor contact in the master controller. This trouble can usually be detected by removing the controller cover, notching up the controller slowly, pushing the contact fingers lightly at each notch with a wooden stick, and noting any arcing or loose contact between the fingers and contact plate. If the contacts cannot be readily adjusted, the train should be operated from the following car.

59. Loose Train-Cable Jumper.—During acceleration, the trainmen should note whether or not the contactors

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are operating in all the cars of the train. If the apparatus in the rear section of the train does not operate, the trouble is probably due to a loose jumper near the front end of the first car that is inoperative.

DEFECTS IN THE MOTOR-CONTROL CIRCUIT

60. Circuit-Breaker.—If one or more of the circuit-breakers open during the operation of the train, return the control handle to the off-position, and move the handle of the circuit-breaker to the on-position. If the circuit-breaker on any car opens repeatedly while starting the train, make a careful examination of the air brakes to see that they have been released properly. If there is no difficulty with the brakes, examine the circuit-breaker to see that it is properly adjusted. If the circuit-breaker is in proper condition and the trouble still persists, the car should be cut out by opening the seven-point cut-out switch beneath the car.

61. Open Circuit in the Bus-Line.—An open circuit in the bus-line may be detected when the train is at a cross-over and no current is obtained on the operating car, although the remaining cars in the train have current. This trouble is due to the blowing of the bus-line fuses or to a disconnected bus-line jumper. If the trouble cannot be quickly remedied, the motorman should go to the first car having current and move the train over the cross-over, after which operation can be continued from the forward car.

62. Blowing of Fuses.—The blowing of the **main motor fuse** on a car prevents the operation of the main motors on that car, although the circuit-breakers may be closed and the contactors in working order. The action is usually caused by a ground on the motors or on the motor circuits. The main-motor fuse rarely blows, since the motors are also protected by the quicker acting circuit-breaker. If it is necessary to renew the main fuse, first open the main switch.

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A **shoe fuse** may blow because of a ground or a short circuit in some part of the car wiring. To insert new shoe fuses on the road, open the third-rail switch and insert paddles between all the third-rail shoes and the third rail.

A **trolley fuse** may blow because of a ground or short circuit in the car wiring, or because of excess current due to running the train with only one trolley in service, thus taking the current for the whole train through one trolley fuse. To replace the trolley fuse on the road, open the trolley switch and pull down the trolleys that are in service.

LONG ISLAND RAILROAD MULTIPLE-UNIT TRAIN

APPARATUS

AUXILIARY CONTROL

63. The auxiliary-control system, sometimes called the master-control system, comprises an electric circuit that actuates certain magnet valves, and is entirely separate and distinct from the motor-control system. The motor-control system takes its current from the trolley or the third rail and regulates the supply of current to the motors. The action of the current-regulating devices in the motor control is governed by the auxiliary-control system.

The auxiliary-control system derives its operating energy from a storage battery, and thus has a complete metallic circuit independent of the higher voltage of the motor circuit and free from ground connections. The auxiliary-control system regulates the action of the main-control system by the action of the master controller in connecting the storage battery mains to the circuits of certain of the valve magnets that control the air supply to the switches of the main-control system.

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These valve magnets when supplied with current operate small air valves that allow air to pass from the control air reservoir to cylinders in which pistons are connected to switches. By admitting air to the cylinders of the different switches in certain order, thus closing the switches, the desired combinations of motors and resistances are secured.

The apparatus constituting the auxiliary control on a motor car is as follows: Master controllers; train line; line relay; series limit switch; control cut-out switch.

A train line, together with its junction boxes and connector sockets, is installed on trailer cars. These devices are used to connect the train line on motor cars that may be separated by a trailer car.

MOTOR CONTROL

64. The apparatus constituting the main control system is as follows: A group of unit switches that change the motor connections and in conjunction with the resistances regulate the supply of current to the motors; a set of resistances that are used in connection with the switch group to control the current supply to the motors; a line switch which is a separate double-break switch and that controls the supply of current to the switch group; a reverse switch that controls the direction of flow of the current through the armatures of the motors and thus governs the direction of motion of the car.

These four pieces of apparatus constitute what might be called the active elements in the motor control. In addition to these devices there is a system of supply mains on each car which carry the current from the third-rail shoes to the apparatus on that car; and there is also a main called a bus-line that runs the entire length of the train. The supply mains on each car obtain current from the third rail through the third-rail shoes and the shoe fuses, and are connected to the bus-line through the bus-line fuses. From the point where the mains from the third-rail shoes and the bus-line join, the circuit passes to the main switch, which is a single-pole quick-break switch mounted on the switchboard panel in one of the cabs of the car. From the main switch the

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circuit passes to the main fuse, the line switch, and to the switch group.

Every motor car is equipped with all of this motor-control apparatus, and every trailer car is equipped with the bus-line connections. On a trailer car the bus-line apparatus consists of two bus-line junction boxes and four bus-line connector sockets. This apparatus is the same as the bus-line apparatus on the motor car except that on the motor car the bus-line is connected to the supply mains through the bus-line fuses.

The connection of the bus-line between cars is made by what is called a bus-line jumper. By this arrangement of a bus-line running through the train, all third-rail shoes are connected in parallel, and if any third-rail shoe is in contact with the third rail, the whole train is thereby connected to the third rail and all the motors of the train may be supplied with current.

INSPECTION AND OPERATION

65. Inspection.—Before starting a train, care should be taken that the air-compressor switches are closed on all of the switchboards, and also that the battery switches on all of the switchboards are both thrown in the same direction (either up or down). Time should be allowed for the air compressor to charge the air reservoirs and the brake train line.

Next see that all main switches are closed, that all the controller switches near the master controller are open, and that no master controller has a handle except the one used for the operation of the train.

66. Forward Operation.—To move the train in the forward direction, close the line switch cut-out switch, move the handle of the master controller to the right of the off-position and then close the brake cut-out switch. If it is desired to make a slow start, the master controller should be advanced to the switching position only, but this position should not be retained longer than necessary, as it is not a running position. If this does not start the train, or the speed is not high enough, one switch at a time of the switch

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group can be made to close by repeatedly moving the master-controller handle to the series-running position and returning it promptly to the switching position. When making ordinary starts in regular service, throw the master-controller handle to the series-running position or multiple-running position, according to the speed desired.

67. Reverse Operation.—The motors on the train may be reversed by moving the master-controller handle to the reverse position. Do not use this means for stopping the train except in case of emergency and to avoid accident.

TRAIN FAILURE

68. Fuses.—In case it is necessary to replace the bus-line fuses or the shoe fuses, remove the bus-line jumper at both ends of the car and insert wooden paddles between the third rail and all the third-rail shoes of that car.

In case it is necessary to replace the main fuses, first open the main switch on the switchboard.

When replacing any fuses in a circuit controlled by a switch, such as in the heat, light, and pump circuits, first open the switch that controls the circuit.

69. Overload-Trip Reset Switch.—Do not use the overload-trip reset switch unless one or more of the trips on the circuit-breakers have operated. The switch must not be constantly used for resetting the trips. If the trip on any car operates repeatedly in service, the car should be cut out by opening the main switch on that car. If there is but one motor car in the train, cut out the No. 1 motor at the control cut-out switch and notch up the master controller as previously described, but do not go beyond series-running position. If the overload trip still operates, cut in the No. 1 motor and cut out the No. 2 motor, notching up the master controller as before.

With either motor cut out at the control cut-out switch, never move the master-controller handle beyond the series-running position.

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BRAKES
(PART 1)

INTRODUCTION

1. When electricity for propulsion purposes began to compete with the horse and the mule, the motors used were of low power and the cars were of the single-truck type and weighed from 7 to 10 tons. Under these early conditions, the speed of the electric cars was low and the type of hand-brake in use on the horse cars was therefore retained. As the electric service developed, the size and weight of the cars were increased, until finally the weight reached the limit for single-truck construction and the double-truck car with greatly increased motive power made its appearance. The greater weight of the cars and the higher speed of the service inaugurated with the advent of the double-truck car made the control of the car by the simple hand-brake so difficult that multiplied-power hand-brakes had to be employed. Later, numerous friction brakes, electric disk brakes, Gerard hand-brakes, and brakes of other kinds were used in the endeavor to have the brake control of the car keep pace with the ever-increasing weight of the cars and the speed of the service.

2. In the earlier days, the first cost of the equipment was the important factor, so that progression in braking power was along the line of the hand-brake. Later, however, the questions of safety, economy of operation, and the saving of time in operation became the important factors, and these led naturally to the adoption of a power brake. The present-

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day equipment of two-truck electric cars intended for individual operation generally includes a reliable form of *straight air brake*, with a *multiplied-power hand-brake* as an auxiliary brake. This equipment makes it entirely safe and practicable to operate the cars at higher speeds, thus permitting a more frequent service than could be maintained at the lower schedule speeds allowable when the hand-brake equipment alone was employed.

The introduction of the interurban, the elevated, and the subway electric-train service, with cars weighing from 50,000 to 98,000 pounds and with schedule speeds of 60 miles an hour, necessitated a still further development of the air brake. Thus, the *emergency straight air brake* and the *automatic air brake* were brought into use.

3. There are several methods of operating electrically propelled trains, each one of which has distinctive features that make a certain air-brake equipment better adapted for that method than for another. In order that the different methods of operation may be thoroughly understood, they will be explained in their proper sequence, after which the brake system most suitable for each method will be taken up. The several methods of operation employed in electric traction work are as follows:

1. *Single-car trains*, in which all cars in the service are operated singly at all times, and are never expected to haul a trailer.

2. *Two-car to three-car trains*, the first car of which is the motor car that hauls the other cars as trailers. The motor car in this method is intended to be operated singly except during rush hours, when trailers are hauled.

3. *Two-car to three-car trains*, the first car of which is the motor car that hauls the other cars as trailers the greater part of the time. In this method, the operation of the motor car singly is of secondary consideration.

4. *One-car to five-car trains*, in which the service includes trains of motor cars and trailers or all motor cars, not exceeding five cars in length.

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5. *Trains of five or more cars*, in which a train consists of all motor cars or of part motor cars and part trailers.

6. *Trains of any length* that are hauled by a completely equipped electric locomotive, all cars in the train being trailers equipped with the automatic quick-action brake of the standard steam-railway type.

The six systems just mentioned cannot properly be controlled by one standard air-brake equipment; each system of train operation requires a particular type of brake.

4. A hand-brake equipment is generally installed on a car or a locomotive as an auxiliary to the air-brake apparatus. The hand-brake may be used to control the car in an emergency, as when the air-brake apparatus is out of order; also,

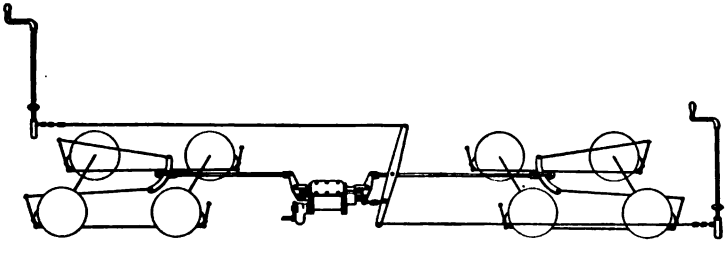

FIG. 1

it may be used to hold the car when the air brake is out of service, as when the car is lying idle on a side track.

In Fig. 1 is shown diagrammatically one method of connecting a hand-brake and an air brake to the system of levers that press the brake shoes against the wheels.

When the handle of the hand-brake is turned, a chain attached to a pull rod is wound around the lower part of the brake staff. The pull rod operates a long lever having its center point fixed to the car body. This lever in turn operates through other levers and connecting pull rods to apply the brake shoes against the wheels, thus stopping the car. By means of the combination of levers, the pressure applied to the wheels is many times greater than that applied to the brake handle by the motorman. When the pressure on the

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brake shaft is released, springs force the brake shoes away from the wheels and thus release the brakes.

When the air-brake apparatus is used, the pressure of the air in the brake cylinder moves the brake piston and its rod and applies the brakes through the action of levers and connecting pull rods. The long lever at the right of the brake cylinder is in this case idle.

There are a number of types of brake riggings, but Fig. 1 shows the general principles of the operation of the brakes from the hand-brake lever or from the piston rod of the air-brake cylinder.

SINGLE-CAR TRAIN SERVICE

CONSTRUCTION OF THE STRAIGHT AIR BRAKE

5. For **single-car train operation,** the standard practice is to use the **straight air brake.** This type of brake, when used in conjunction with a hand-brake, forms a safe brake system that is of low first cost, simple of construction, positive in control, and easy to manipulate. One of its great advantages lies in the fact that the amount of pressure in the brake cylinder can be increased or decreased at will and with great accuracy. This feature is of special value when the car is coasting down a long, variable grade, or if a close, accurate stop at a given point is to be made.

6. A diagrammatic view of the **General Electric straight air brake** is shown in Fig. 2. The system consists essentially of a supply of compressed air stored in a main reservoir, a brake cylinder, and a brake valve. By the operation of the brake valve, the motorman can admit air from the main reservoir into the brake cylinder so as to set the brake, or he can exhaust the air from the brake cylinder so as to release the brake. The names, as well as the operation, of the various parts of this brake will now be taken up.

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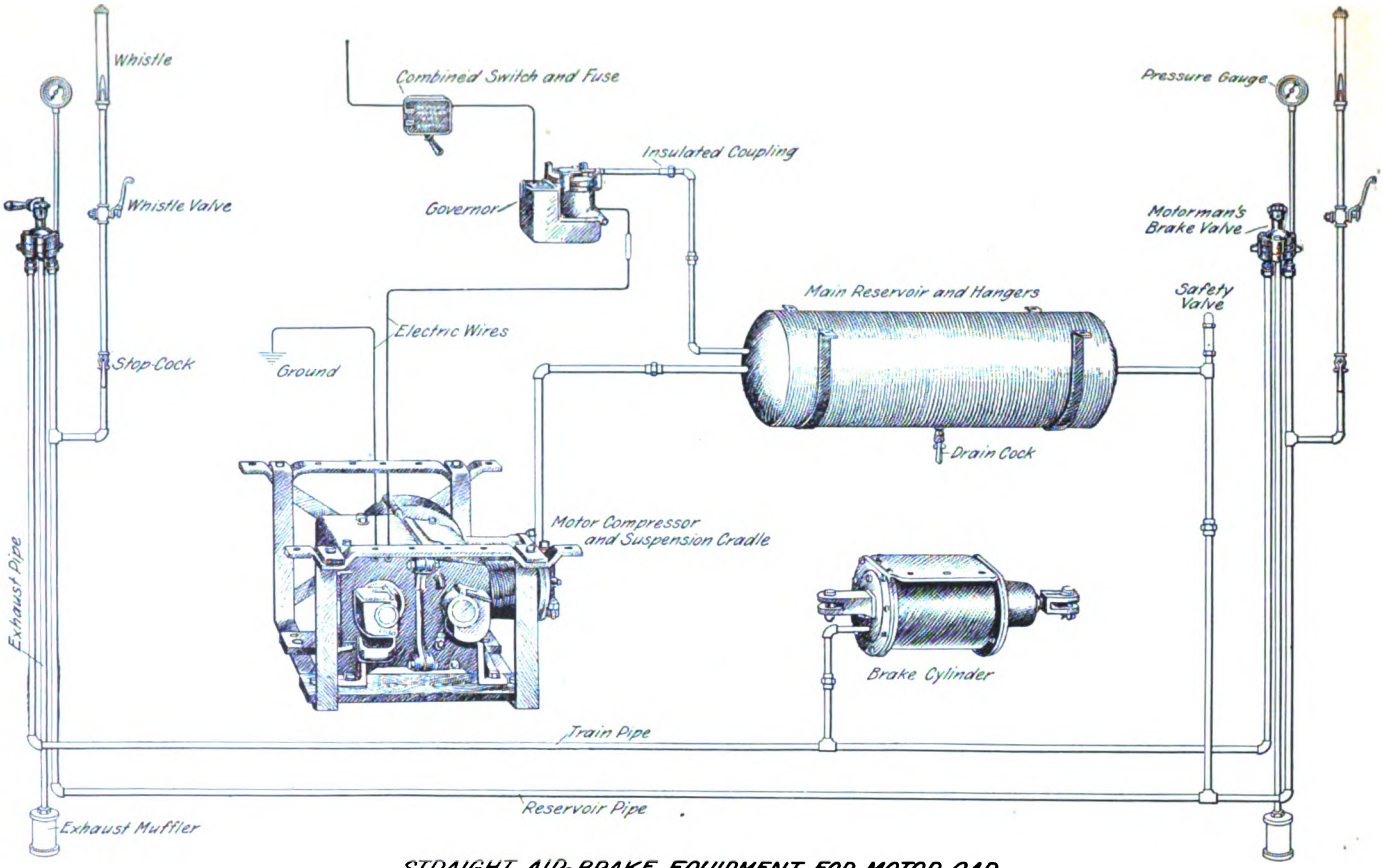

STRAIGHT AIR-BRAKE EQUIPMENT FOR MOTOR CAR

FIG. 2

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7. Motor Air Compressor.—The **motor air compressor,** or *air pump,* as it is often called, compresses the air and stores it in the main reservoir for use in the brake system. It is controlled by the pump governor.

8. Governor.—The **governor** is simply an automatic switch in the form of a combination electric-pneumatic device. The electric part consists of a switch in the electric circuit of the compressor, while the pneumatic part consists of an air cylinder that is operated by main-reservoir pressure to open and close the switch at the proper times, thus stopping and starting the compressor motor. The pneumatic part is piped to the main reservoir and is always charged to main-reservoir pressure. It is so adjusted that when the main-

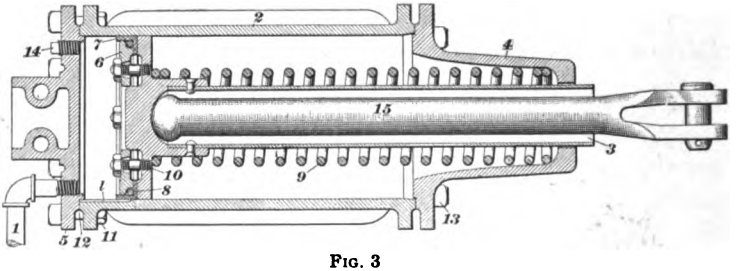

FIG. 3

reservoir pressure falls below a predetermined amount, the governor will start the compressor and charge the main reservoir with air. When the main-reservoir pressure reaches the amount for which the governor is adjusted, the governor will stop the compressor, which will then remain idle until the pressure in the reservoir is again reduced to the amount for which the lower adjustment of the governor is made.

9. Brake Cylinder.—A cross-section of the **brake cylinder** is shown in Fig. 3. Air entering through the brake-cylinder pipe *1* forces the piston to the right and sets the brake. When the air is exhausted from the cylinder, the release spring *9* will force the piston to the left to release position. The springs in the brake rigging will then act to release the brake shoes from contact with the wheels. The

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piston is attached to a hollow sleeve *3*, and the push rod *15* and its crosshead are made separate from the sleeve so that the hand-brake can be applied without moving the piston and wasting part of the braking force. The packing expander ring *8* is for the purpose of holding the packing leather *7* against the cylinder wall to prevent air from escaping past the piston before the packing leather is set out by the air pressure.

10. Motorman's Brake Valve.—The **motorman's brake valve,** Fig. 2, is connected to both the main-reservoir pipe and the brake-cylinder pipe and controls the admission of air to the brake cylinder and the exhaust of air from it. As the car is intended to be run from either end, a motorman's brake valve is placed at each end of the car.

This brake valve has three positions of its handle, namely, *application*, *lap*, and *release*, lap being the central position.

In the **application position,** the valve admits air into the brake cylinder and sets the brake. This position is divided into two parts, namely, the *service-application position* and the *emergency-application position*. The former brings a small port into use and sets the brakes gradually; the latter opens a large port and applies the brake with full force instantly. The emergency position is used in cases of actual emergency, as when the car must be stopped in the shortest distance possible.

In the **lap position** the valve covers all ports so that any air admitted to the brake cylinder is retained there. This position is used while holding the brakes on.

The **release position** connects the brake cylinder with the atmosphere and releases the brakes. Detailed instruction regarding the air passages in the brake valve will be provided later in connection with some of the other types of valves.

11. Exhaust Mufflers.—The **exhaust mufflers** are used to soften the noise of the air exhausting from the brake cylinder. An exhaust muffler consists of an iron box that has a cross-sectional area several times greater than the cross-

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sectional area of the exhaust pipe and that is filled with curled hair held in place by means of metal screens. The air expanding suddenly at the muffler and being divided by the hair into numerous fine streams, escapes to the atmosphere without noise.

12. Safety Valve.—The **safety valve** in the main-reservoir pipe serves to prevent too high a pressure from accumulating in case the governor fails to stop the compressor motor when the maximum pressure is reached.

13. Air Gauges.—The **air gauges,** one of which is located at each end of the car, are connected to the main-reservoir pipe so that the motorman can see at all times just how much pressure is being carried in the main reservoir.

14. Drain Cock.—The **drain cock** in the main reservoir is used to drain the water from the main reservoir. The air as it is compressed is heated by the process and carries moisture with it into the main reservoir, where the moisture is deposited as water when the air cools. This reservoir should be drained frequently.

15. Similar Air-Brake Systems.—The straight air-brake systems of the Allis-Chalmers Manufacturing Company, the National Air Brake Company, and the Westinghouse Traction Brake Company are similar in operation to the one just described, differing merely in the details of the apparatus used. They will therefore not be treated of.

OPERATION OF THE STRAIGHT AIR BRAKE

16. Before taking a car on a trip, care should be taken to see that everything is in proper order. The pressure of the air in the main reservoir should be sufficient for the proper operation of the brakes, and the brake-valve handle should work freely and properly. The brakes should be tested both in service and in emergency positions, as will be explained later, to make sure that they are working all right and that

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no improper connections have been made. Also, the hand-brake, if applied, should be released before starting.

17. The straight air brake is applied by admitting air from the main reservoir into the brake cylinder, and it is released by exhausting the air from the brake cylinder to the atmosphere. After learning the notches that correspond to the several positions of the motorman's brake-valve handle, it is an easy matter to operate the brake. However, considerable practice, as well as the exercise of good judgment, is needed to make the smooth, quick, accurate stops that are required in service.

The brake is released by moving the brake-valve handle to the extreme left, which is the *release position*. The first notch to the right of the release position is the *lap position*, which is used to lap the valve. The next notch to the right is the *service notch*, which serves to set the brake gradually, and the position at the extreme right is the *emergency position*, which is used to set the brake instantly with full force.

18. *To set the brake gradually*, move the handle to the service notch for a short interval, and then move it to lap position to hold the brake applied. If it is desired to increase the braking power, again move the handle to service position and then back to lap; this may be repeated until the desired braking power is obtained. As a large quantity of compressed air can flow through the small port in the brake valve in a short time, it is necessary in order to make a light application of the brakes to move the brake valve to service position and then quickly back to lap position.

To reduce the power of the brake partly, move the brake-valve handle to release position and almost immediately return it to lap. This allows a portion of the air to escape from the brake cylinder, reducing the power of the brake. Repeat this operation as necessary. After entirely releasing the brake, carry the brake-valve handle in release position.

To make a quick, smooth stop from speed, apply the brake with a pressure of 25 or 30 pounds when the car is moving at high speed, and gradually release the brake-cylinder pres-

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sure as the speed drops until a pressure of about 10 pounds is retained in the cylinder. This pressure should be retained until the car stops. In case a gauge showing brake-cylinder pressure is provided, the varying pressures will be indicated on the gauge. In case no gauge is provided, the motorman will be guided by experience and for the first application of the brake, somewhat by the amount of reduction of main-reservoir pressure as indicated by the gauge shown in Fig. 2. Experience will soon show the distance required to stop from any speed when making the stop quickly, smoothly, and with but one application of the brake. The one-application method will be found to give much better results than the method in which several applications and releases are made during the stop.

To make an emergency stop, throw the brake valve into emergency position instantly, turn off the electric power, and apply sand to the rails.

To start the car after making a stop, first move the brake-valve handle to release position and then turn on the current.

19. In descending a grade, care should be taken not to put the brake on too hard at the start. First, make a moderate application and lap the valve long enough for the brake to take effect. If the speed is still too high, increase the application slightly and repeat as often as necessary to control the speed properly. On a long, varying grade the brake-cylinder pressure should be increased or decreased to suit the grade.

If a car is to be left standing for some time, the hand-brake should always be set before leaving. It is possible that some person might intentionally or unintentionally release the air brake and thus permit the car to run away, provided it is on a grade.

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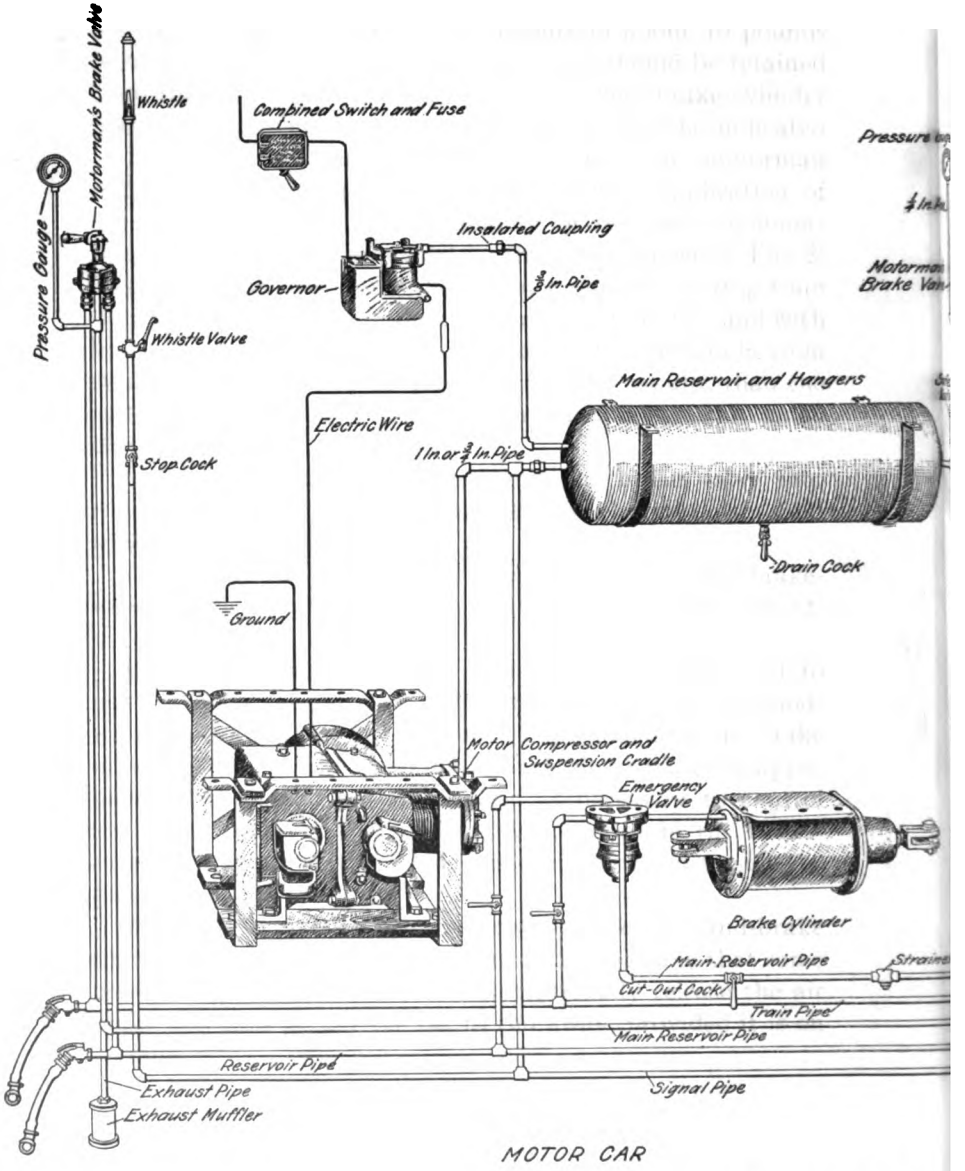

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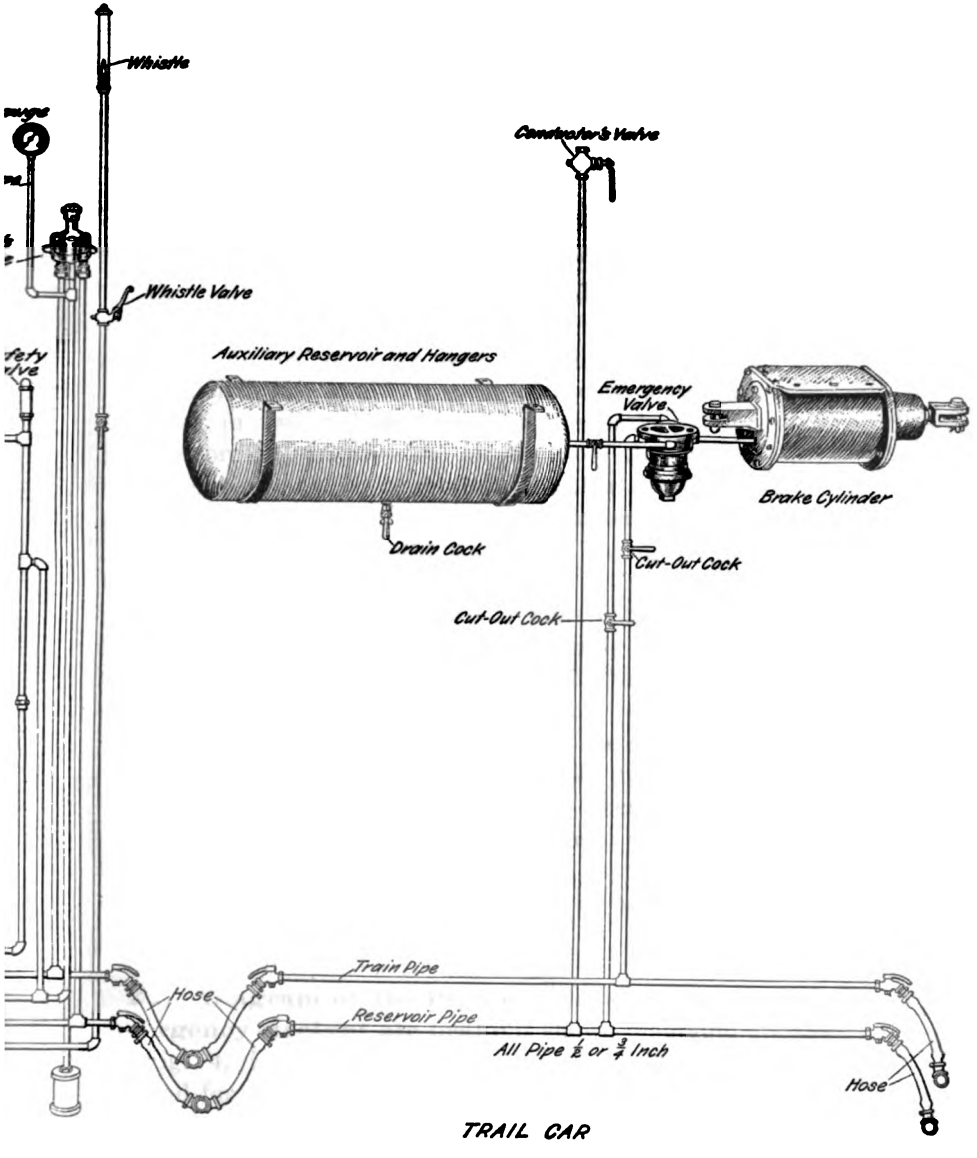

TRAIL CAR

GHT AIR-BRAKE EQUIPMENT

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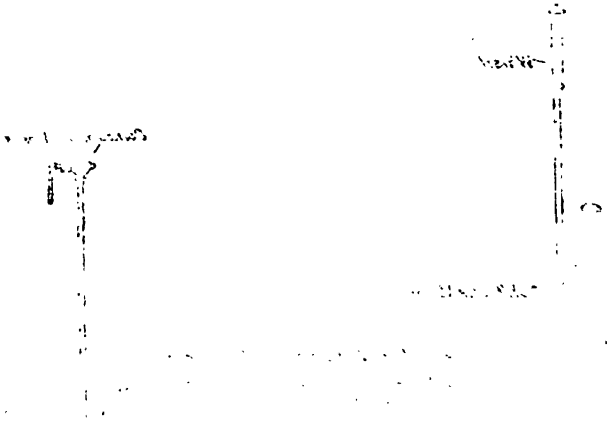

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SINGLE-CAR AND SHORT-TRAIN SERVICE

CONSTRUCTION OF THE EMERGENCY STRAIGHT AIR BRAKE

20. Although the straight air brake is used advantageously on single-car trains, it has a serious defect when used on trains of two or more cars. In the latter service, the straight air brake would be rendered useless if the train were to break in two, a hose burst, or the brake-cylinder pipe become broken, because the air to apply the brakes would then escape to the atmosphere. Another drawback to the straight air brake in such service is that only the motorman can control the brakes, the conductor having no control of the brake whatever.

In the case of a train of two or more cars, it is necessary that the conductor shall be able to apply the brakes from any car in the train, and also that the brakes shall apply automatically if the train breaks in two.

In order to overcome these defects of the straight air brake and to adapt that type of brake to short-train service, there was designed an emergency valve that, when used in connection with a new type of motorman's brake valve, constitutes a straight-air system that is known as the **emergency straight air brake.** It is this type of brake that is used for single-car and short-train service.

21. Diagram of the Piping.—The **General Electric emergency straight air brake** is shown diagrammatically in Fig. 4, in which the brake equipment for a motor car and for one trailer are shown. In addition to the reservoir pipe and train pipe of the straight air-brake system, there is provided a main-reservoir pipe that connects to the brake valve, which in this type of brake has four pipe

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connections instead of three. A separate signal pipe also is used on the motor car.

The train pipe and the reservoir pipe extend throughout the train, connecting the motorman's valves and the emergency valves. Instead of extending the main-reservoir pipe throughout the train, it is used on only the motor cars, the auxiliary reservoirs being substituted for it on the trailers. These reservoirs are charged through the emergency valves.

22. The reservoir pipe is always charged to main-reservoir pressure. The train pipe admits air to the brake cylinder during service applications and exhausts air from it when the brakes are released in exactly the same way as in the straight air-brake system. In emergency applications, either produced by the brake valve or caused by a break-in-two, a burst hose, or some similar accident, the emergency valve operates and charges the brake cylinder direct from the reservoir pipe. This brake system, therefore, consists of a straight air brake for making ordinary stops and for maintaining control of the train on grades, and a plain automatic emergency brake for making short, quick stops in emergencies and for automatically stopping the train if it breaks in two or if any part of the reservoir pipe happens to burst. If the train pipe separates or breaks, however, the brake will not set automatically, because this pipe does not contain air pressure; consequently, a break in the train pipe will not be discovered until the motorman attempts to make a service stop, when the brake will fail to apply. In an event of this kind, the motorman would have to apply the brakes from emergency-application position of the brake valve in order to stop the train.

23. In this system of brakes, the conductor can apply the train brakes from any car by opening the conductor's valve and making a reduction in reservoir-pipe pressure. This action will operate the emergency valve and set the brakes with main-reservoir pressure.

If necessary, a trailer car equipped with straight air brakes can be operated with a motor car equipped with the emergency straight air brake by simply coupling up the train pipe and

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closing the rear angle cock in the reservoir pipe on the motor car.

With the exception of the motorman's valve, the emergency valve, and the conductor's valve, all the apparatus of the emergency straight air brake is the same as that used in the straight air brake.

24. Motorman's Brake Valve. — The brake valve used with the emergency straight air brake is shown in Fig. 5. It has four pipe connections. Connection *1* connects with the main-reservoir pipe; *2*, with the reservoir pipe; *3*, with the train pipe; and *4*, which is located in the center of the valve (not shown in the figure), with the exhaust pipe.

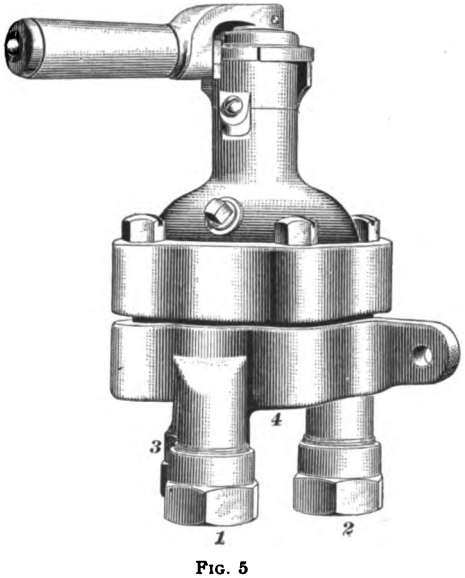

FIG. 5

25. There are five positions of the valve handle, namely, *emergency-release position*, the first position on the extreme left; *service release and running position*, the first position to the right of emergency-release position; *lap position*, the next position to the right; *service-application position*, the next position on the right; *emergency-application position*, the position to the extreme right.

26. The **emergency-release position** is used to release the brakes after they have been applied by an emergency application. When the brake handle is placed in emergency-release position after an emergency application of the brakes, the brake valve connects the train pipe with the

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exhaust pipe, allowing the brake-cylinder air to escape through the motorman's brake valve to the atmosphere and thus release the brakes. The brake valve at this position connects the main-reservoir pipe, through a small port, with the reservoir pipe, so that the reservoir pipe is recharged to main-reservoir pressure. This small port is of such size that should the train part when the brake-valve handle is in the emergency-release position, the air cannot escape through the small port and the open reservoir pipe faster than the motor compressor can supply the air, so that reservoir pressure will be maintained.

27. The **service-release position** is used to release the brakes after a service application has been made; also, the brake handle is carried in this position during the time that the brakes are released. When the handle is in this position, the brake valve connects the train pipe with the exhaust pipe, thus making direct communication between the brake cylinders and the atmosphere. There is no connection, however, between the main-reservoir pipe and the reservoir pipe, so that no air can pass through the brake valve into the reservoir pipe, but reservoir pressure is maintained through the emergency valve on the motor car, as explained later.

28. In the **lap position** all ports are covered or blanked, so that no air can pass through the valve. After the brake-valve handle has been moved to service position to apply the brakes, it is moved to lap position to hold them on. Lap position is the only position in which the brake-valve handle can be removed or put on.

29. The **service-application position** is used in making all service stops and when applying the brake on grades. In this position, the valve connects the main-reservoir pipe directly to the train pipe, admitting air to the brake cylinder and applying the brakes.

The service-application position is divided into two parts: *first-service position*, in which air is admitted into the train

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pipe through a small port that permits the brakes to be applied gradually for a slow-down or ordinary service stop; and *full-service position*, in which a large port admits air into the train pipe and thus applies the brakes rapidly. This latter position corresponds to the emergency position of the straight air-brake valve and is used advantageously as such when the motor car is operated singly.

30. The **emergency-application position** is the one from which the brakes should be set in case of emergency. In this position, the valve connects the reservoir pipe with the exhaust pipe, causing a reduction of reservoir-pipe pressure. This operates the emergency valves and causes them to admit air directly from their respective reservoirs into the brake cylinders, applying the brakes to their fullest extent. Any sudden reduction of reservoir-pipe pressure, such as would be caused by the parting of a train or the bursting of a reservoir hose, will cause an emergency application of the brakes, as just explained.

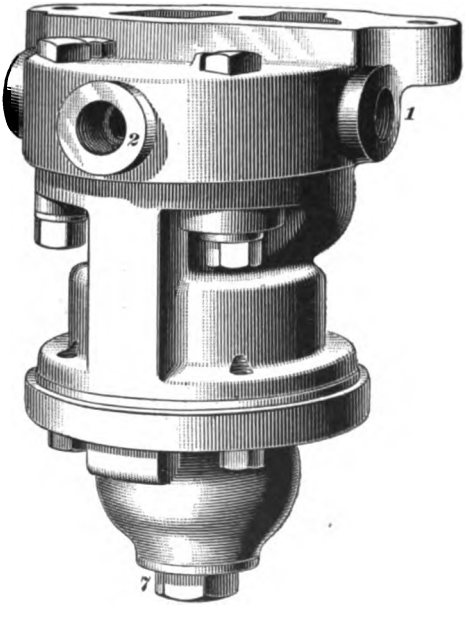

FIG. 6

In the emergency-application position, the brake valve cuts off the connection between the main reservoir and the brake pipe and thus prevents main-reservoir pressure from escaping through the brake pipe to the atmosphere in case the train parts or the reservoir pipe or hose bursts.

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31. Emergency Valve.—The **emergency valve** and its pipe bracket are shown in Fig. 6. Two of the four pipe connections are shown. That marked *1* connects with the train pipe, and that marked *2*, with the reservoir pipe.

In Fig. 7 is shown the reservoir pipe connection and the main-reservoir pipe connection. Pipe connections to the brake cylinder lead to a cavity x surrounding the slide-valve bushing *5*, and the train-pipe connection leads to another cavity y.

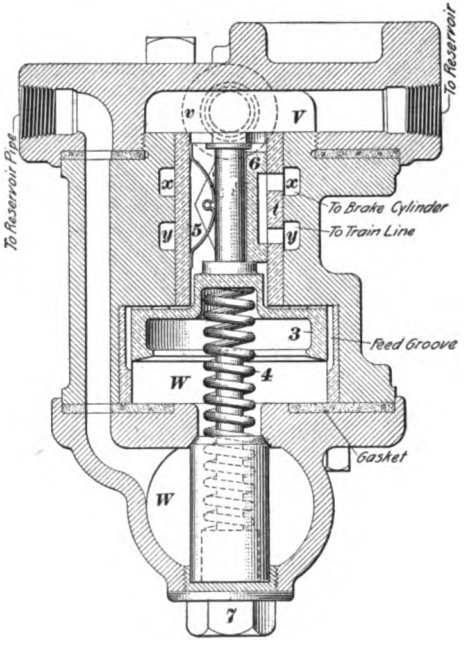

FIG. 7

The mechanism of the emergency valve consists of a piston *3* that operates a slide valve *6*. Every time the piston moves, its stem engages the slide valve and causes it to move. The piston is moved downwards by lowering chamber W pressure below chamber V pressure, which causes the piston to be forced downwards against the action of a spring *4*. Raising chamber W pressure equal to chamber V pressure will cause the spring *4* to move the piston and the slide valve upwards to their normal positions.

The spring *4* is made of such strength and the feed-grooves are so proportioned that there is no danger of the piston *3* moving to emergency position when a service application of the brakes is made. Also, the spring will hold the piston *3* in its normal position unless a sudden, positive reduction of reservoir-pipe pressure is made. Any dirt and moisture that

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may accumulate in chamber *W* can be removed by taking out the screw plug *7*.

32. The figure shows the parts of the emergency valve in the positions they maintain at all times except when the valve is operating for an emergency application of the brakes. The spring *4* holds the valve parts in such positions that free communication is maintained between chambers *W* and *V* through the feed-grooves. Thus, air from the reservoir pipe can flow through the grooves past piston *3* into chamber *V* and thence into the auxiliary reservoir on the trailer. All air that leaks from the reservoir pipe and the auxiliary reservoirs is made up, and the proper pressure maintained, by main-reservoir air passing through chamber *V* of the emergency valve on the motor car, the feed-grooves, and chamber *W*, into the reservoir pipe and auxiliaries.

33. In the normal position of the emergency valve, the train pipe is connected to the pipe leading to the brake cylinder by the cavity *t* of slide valve *6*. Air is thus free to pass either into or out of the brake cylinder through the emergency valve.

34. The movable parts of the emergency valve are held in their normal positions, as shown in Fig. 7, by the spring *4*, both while the brakes are released and during a service application of the brakes. The slide valve *6* does not move, and the normal operation of the brakes of the train is exactly the same as that for the straight air brake.

When operating a train in which all the cars are provided with compressors, the air taken from the main reservoir of the first car to set the brakes for service stops would soon reduce that pressure to the limit for which the governor is set to start the compressor, if it were not for the fact that this reservoir quickly equalizes with all the others through the feed-grooves in the emergency valves and the reservoir pipe. By maintaining the pressures equal in all the reservoirs, each compressor is made do its share of the work.

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35. An **emergency application,** brought about by a sudden reduction in the reservoir-pipe pressure, either through the action of the brake valve or the conductor's valve, or by other means, causes piston *3* and the slide valve *6* to move downwards. This movement of the slide valve *6* first closes the feed-grooves and then the port *y* leading to the train pipe. When the slide valve *6* has moved past the port *x*, a direct communication for the flow of air is formed between the reservoir and the brake cylinder through chamber *V* and port *x*. The brakes are then set. Piston *3* moves down until it comes in contact with the leather on the gasket, when its edge is pressed into the gasket until it makes an air-tight joint. This cuts off all flow of air to or from chamber *V* and the reservoir pipe.

36. In the case of an **emergency release,** following an emergency application, the reservoir-pipe pressure must be raised until it is about equal to the pressure in the reservoirs, when the spring *4* in the emergency valve will force the piston *3* to its normal position and the brakes will be released. To accomplish this action, the motorman places the brake valve in the emergency-release position, which connects the train pipe with the atmosphere and also allows air from the main reservoir on the first car to flow into the reservoir pipe through a small port in the brake valve, thus recharging the reservoir pipe and the auxiliary reservoirs on the trailers. A small port is used for this purpose, in order that the pressure will rise at about the same rate in all parts of the reservoir pipe, thus releasing all emergency valves at about the same instant. When the slide valve *6* is in its normal position, the air in the brake cylinder can exhaust to the atmosphere through cavities *x* and *y* and the train pipe, which is now open. The brakes will then be released. A pressure of 70 pounds is usually carried in the reservoir pipe.

37. Similar Emergency Air-Brake Systems.—The principle of operation of the emergency straight air brake systems of the National Air Brake Company, the Allis-

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Chalmers Manufacturing Company, and the Westinghouse Traction Brake Company is the same as that of the General Electric system, the apparatus differing merely in detail. Therefore, the other systems will not be treated of.

OPERATION OF THE EMERGENCY STRAIGHT AIR-BRAKE SYSTEM

38. In treating in a general way of the operation of the emergency straight air-brake system, it should be borne in mind that the system really consists of two distinct brakes, namely, a straight air brake used in all ordinary brake operations and a simple form of automatic brake that comes into use only when the motorman must make an emergency application of the brakes, when the conductor sets the brakes from one of the trailers, when the train parts, or when the reservoir pipe is ruptured.

39. Service Applications.—Inasmuch as all service applications are made with the straight air feature of the brake, the instructions given for operating the straight air-brake system applies in this case and therefore need not be repeated.

40. Emergency Applications.—The emergency feature of the brake should not be resorted to by the motorman unless there is a real emergency that calls for the shortest stop possible. In that event, the brake valve should be thrown from whatever position it occupies to the emergency position, where it should be left until the train stops or until the danger is past. If it is found that the stop cannot be made in time with the brake alone, as a last resort, to prevent collision or to save life, the motors should be reversed. To reverse the motors, throw the reverse handle in the opposite direction to its direction for normal operation and place the controller handles on the second notch. This notch usually gives the greatest retarding effect. After an emergency application, the brakes must be released by moving the brake handle to the emergency-release position.

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41. Unexpected Emergency Applications.—In case the brakes apply with quick action and without apparent cause, the motorman should immediately place the brake valve in the lap position so as to save the main-reservoir air. In this way provision is made for a prompt release of the brakes and for the recharging of the auxiliaries when the trouble producing the application is discovered and overcome.

If the trouble is due to a burst in the reservoir pipe or hose, close the first cock in the reservoir pipe (but not that in the train pipe) ahead of the break and bleed off the brake; then empty the reservoirs back of it by opening the drain cocks in the bottom of the reservoirs. The motorman can use the straight air feature for ordinary stops on all cars, and if necessary he can release, recharge, and operate the brakes ahead of the closed cock with the automatic feature of the brake until the trouble is repaired.

If the burst is in the cross-over pipe leading from the reservoir pipe to the emergency valve, and it is on the emergency valve side of the cut-out cock, close the cock and drain the reservoir of that car through the drain cock. This will merely cut the automatic or emergency feature of that one brake out of service. A brake should be cut out only when it is in such condition that it cannot possibly be operated.

If the burst in the cross-over pipe is between the cut-out cock and the reservoir pipe, proceed as in the case of a burst reservoir pipe. The brakes on the other cars must be released by moving the brake handle to the emergency-release position since the brakes were set by an automatic emergency application.

42. Use of Conductor's Valve.—In the event of an emergency of which the motorman is unaware, the conductor can set the brake by means of the conductor's valve. To do so, the valve should be held wide open until the train stops. If the conductor's valve is allowed to close and the brake valve is not on the lap position, but is on the running position, the brakes will be released. After the train has stopped, and before leaving the conductor's valve, care should be taken to

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see that it is properly closed. The motorman knowing that he has not applied the brakes, should lap his brake valve just as soon as he feels the brakes go on. The motorman may release the brakes after they have been applied by the conductor's valve by moving the brake valve to emergency-release position.

43. Brake Releases.— If the brakes release after a service application, the trouble may be due to any of the following causes: A brake valve in one of the cars may be in service-release position; a train-pipe hose may be uncoupled; the front or rear angle cock in the train pipe may be open; or the train pipe or hose may have burst. An inspection of these points should be made, and when the fault is located the disorder should be corrected.

44. Setting Out Cars.—In order to set out a car, it will be necessary first to close the angle cocks in the train pipe and reservoir pipe on both sides of the hose to be parted. The hose should then be parted by hand and hung properly. The hose should never be jerked apart by pulling the cars apart; such treatment quickly ruins the hose and causes the piping to leak. The hand-brake must always be set before leaving the car, but before setting it the air brake must be released. In some brake arrangements, the air brake and the hand-brake work against each other; therefore, if the hand-brake is set up while the air brake is applied, the leaking off of the air brake will release the brakes.

45. Cutting Out a Brake.—A brake should never be cut out unless it cannot possibly be operated safely, because cutting out the brake on one car of a three-car train reduces the braking power one-third. To cut out a brake, close the cut-out cocks in the pipes leading from the train pipe and from the reservoir pipe to the emergency valve; then open the drain cock in the auxiliary reservoir and leave it open so that no pressure can possibly accumulate there and cause the brakes to drag on that car.

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If only the automatic features of the brakes are to be cut out, close only the cock in the pipe leading from the reservoir pipe to the emergency valve and drain the auxiliary reservoir. If only the straight air feature of the brake is to be cut out, close the cut-out cock in the pipe leading from the train pipe and do not drain the reservoir.

TWO-CAR TO THREE-CAR TRAIN SERVICE

PLAIN AUTOMATIC BRAKE WITH GRADUATED-RELEASE FEATURES ON THE FRONT MOTOR CAR

CONSTRUCTION OF THE BRAKE

46. Since the third method contemplates having the motor car used continually in connection with other motor cars or trailers in the form of a train, a straight air brake for handling the motor car singly is unnecessary. On the other hand, it is desirable to use a straight air release for the brake of the first, or motor, car; in addition, it is desirable that several brake applications can follow one another immediately without reducing the pressure in the auxiliary reservoir to a dangerous extent.

These requirements can be met better with automatic brakes than with straight air brakes. Accordingly, the Westinghouse Traction Brake Company designed a plain automatic brake known as the **A. M. S. brake** for this service; A. M. S. is an abbreviation for automatic motor equipment with type S triple valve.

47. Pipe Arrangement of the A. M. S. Equipment. The A. M. S. equipment is shown diagrammatically in Fig. 8, which illustrates a motor equipment and a trailer equipment. If the entire train were made up of motor cars, each car would

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have a brake equipment like that of the motor car. Comparing Fig. 8 with Fig. 4, it will be seen that the triple valve has replaced the emergency valve, that a different style of brake valve is used, and that the system of piping is different. With these exceptions, practically similar apparatus is used. In this system, the reservoir pipe is done away with, the brake pipe alone extending through the train. This pipe is connected to the brake cylinder and auxiliary reservoir through the triple valves.

48. The air from the compressor flows through radiating pipes into the main reservoirs. Radiation is provided for the purpose of cooling the air sufficiently before it passes into the brake system, so that it will deposit its moisture in the main reservoirs, where it can readily be drained off without affecting the brake.

It should also be noted that there are a safety valve and a feed-valve in the main-reservoir pipe. The feed-valve connects with the feed-valve pipe that leads to the brake valves. The safety valve protects against excessive main-reservoir pressure. The feed-valve automatically maintains standard pressure (usually 70 pounds) in the feed-valve pipe, and when the brake valve is in release position, the feed-valve maintains standard pressure in the brake pipe.

A duplex, or double, air gauge is so connected in this equipment that its black hand indicates brake-pipe pressure and its red hand main-reservoir pressure.

49. Brake Valve.—The brake valve has four pipe connections that join this valve to the brake-cylinder exhaust pipe, the feed-valve pipe, the brake pipe, and the brake-valve exhaust pipe. The feed-valve pipe leads to a chamber surrounding the rotary valve of the brake valve. This chamber, therefore, is always charged to feed-valve pressure. The rotary valve is so called because it is rotated by means of the brake-valve handle to open and close the brake-valve ports. The brake valve has five positions of its handle. The *release and running position* is at the extreme left, and to the right

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of this is the *holding position*. Then follow in order the *lap*, *service*, and *emergency positions*.

50. The **release and running position** is the position in which the handle is carried at all times, except when setting the brake, holding it on, or releasing the trailer brakes by means of the holding position. The brake-cylinder exhaust is at this position connected to the atmosphere. A connection is made between the feed-valve pipe and the brake pipe, so that air at feed-valve pressure passes into the brake pipe and raises the pressure there to release the brake. The air recharges the brake pipe and auxiliaries and maintains their pressures at the pressure for which the feed-valve is adjusted, usually 70 pounds.

51. The **holding position** of the brake valve is the position in which the brakes on the trailer are released and the brake on the motor car is held on. The motor equipment shown in Fig. 8 is provided with a pipe, called the *brake-cylinder exhaust pipe*, that connects the exhaust port of the triple valve with the brake valve. In the holding position of the brake valve, the pressure is raised in the brake pipe of both the motor car and the trailer cars, and all the triple valves move to release position. The brakes on the trailer cars therefore release, but the motor car brake does not. The air from the motor-car brake cylinder is prevented from escaping through the brake-cylinder exhaust pipe and the brake valve because of the action of the brake valve, which laps the exhaust port when the valve is in the holding position and thus holds the motor brake on. In order to release the motor brake, the brake valve should be moved from holding to release position.

52. In the **lap position** the brakes are held applied for a time. In this position the port leading into the brake pipe is blanked, so that air can neither pass into nor out of the brake pipe through the brake valve.

53. The **service position** is used either to apply the brakes in making ordinary service stops or to control the train

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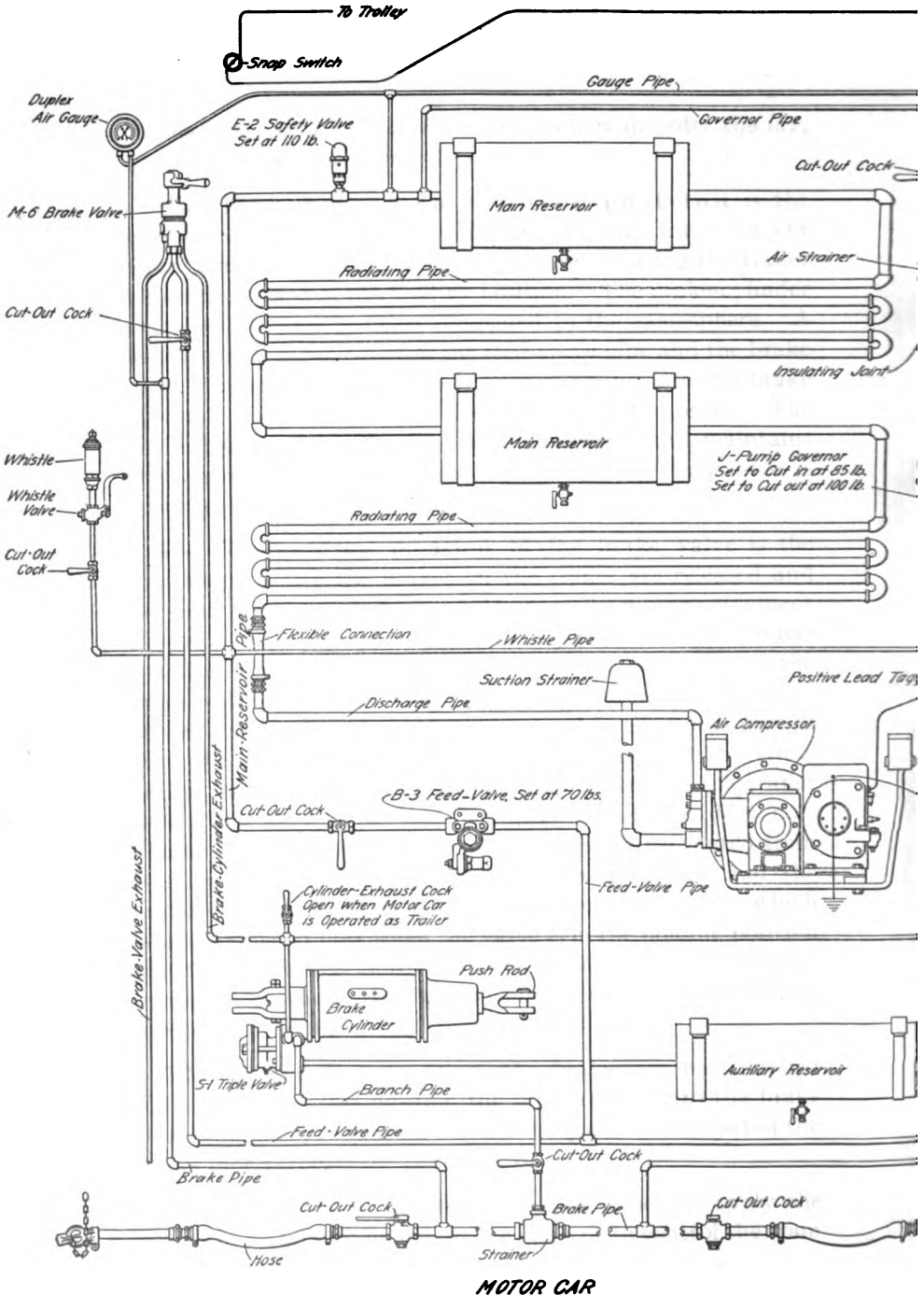

MOTOR CAR

Fig. 8

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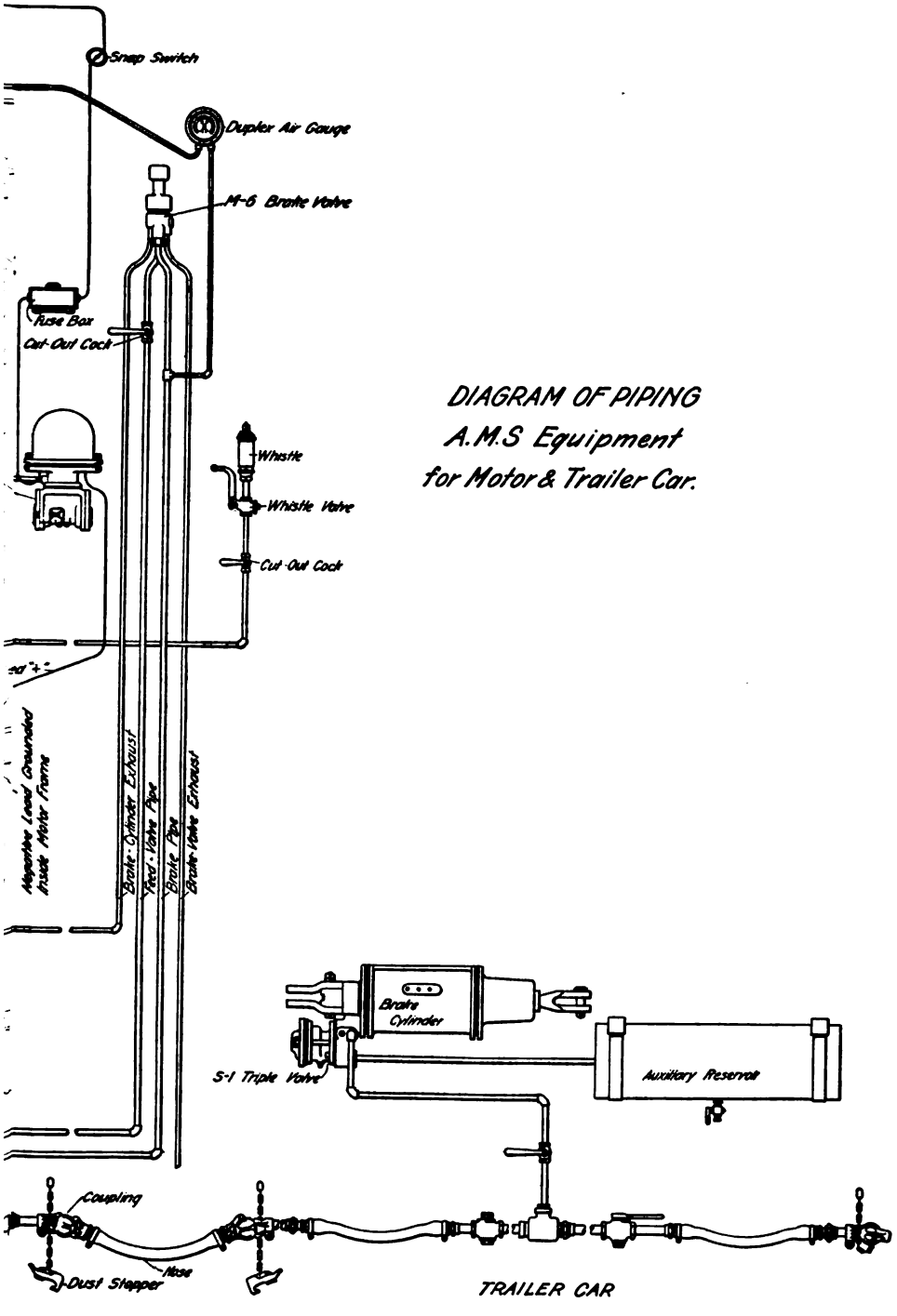

DIAGRAM OF PIPING
A.M.S Equipment
for Motor & Trailer Car.

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on grades. In this position the brake pipe connects with the brake-valve exhaust pipe through three small ports, allowing brake-pipe air to escape gradually to the atmosphere, thus reducing brake-pipe pressure and setting the brakes.

By a *service*, or *graduated*, *application* of the brakes is meant a gradual application of the brakes to control the speed of the train or to make an ordinary stop by bringing the train to rest gradually. The brakes may either be fully or only partly set, and one or several reductions may have been made.

In a *full-service application*, the brake is set with the full force of the air in the auxiliary reservoir as the auxiliary and brake cylinder equalizes their pressures.

By *reduction* is meant a lowering of brake-pipe pressure. A reduction will cause an application of the brakes, although there may be several reductions made for the one application. Each time the brakes are applied and released, the operation is referred to as an application of the brakes, no matter whether one or several reductions are made.

By an *emergency application* of the brakes is meant an application in which the brakes are applied with their maximum force instantly.

54. The **emergency position** should be used in emergencies only, when the shortest possible stop must be made. The brake valve connects the brake pipe with the brake-valve exhaust pipe through a large port, producing a sudden reduction in brake-pipe pressure and applying the brakes to their fullest extent in the quickest time possible.

The applications of the A. M. S. brakes are made in exactly the same way as those of the automatic feature of the emergency straight air brake. The brake pipe is charged to feed-valve pressure at all times except when the brakes are being applied. To apply the brakes, either in service or emergency position, brake-pipe pressure is reduced, and to release them, brake-pipe pressure is raised above auxiliary-reservoir pressure. These changes in brake-pipe pressure in turn cause the triple valve to operate to apply or to release the brake, as the case may be.

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55. Type S Triple Valve.—The *triple valve* is so called because it has three operations to perform. It connects the brake pipe with the auxiliary reservoir to charge the reservoirs; the auxiliary reservoir with the brake cylinders to set the brake; and the brake cylinder with the atmosphere to release the brake.

The **type S triple valve** used with the A. M. S. system is the simplest type of quick-action triple without a graduating valve. It has, however, a quick-recharging feature, through the action of a check-valve of such capacity that, when in release position, the auxiliary-reservoir and brake-pipe pressures are maintained equal; that is, the auxiliary pressure begins to rise when the brake-pipe pressure does, and it keeps equal to this pressure. On this account, a prompt response of the brake is assured at any stage of recharging, because the triple valve will respond just as quickly to a reduction during recharge as it will when the system is fully charged. Hence, one application can follow another in quick succession if necessary. A graduated application can be made with the brake, but the triples will not permit the brake to be graduated off. As already explained, however, the motor-car brake can be graduated off, because the exhaust port of that triple valve is piped to the brake valve. Thus, by using the holding position, the motorman can at will retain all the air in the brake cylinder on the motor car, can exhaust it all at once, or can exhaust it a little at a time to graduate the brake off. The system thus permits of considerable flexibility of operation.

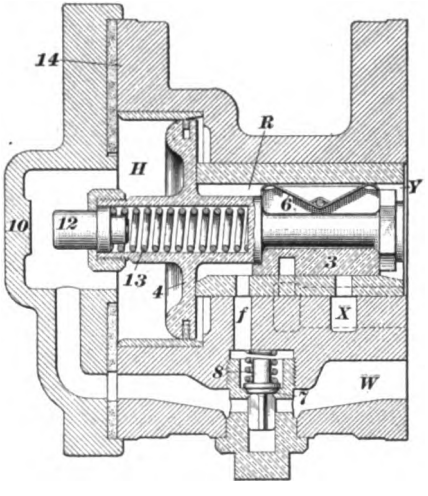

FIG. 9

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56. The general construction of the triple valve is illustrated in Fig. 9, which shows a sectional view through the

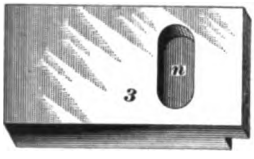

FIG. 10

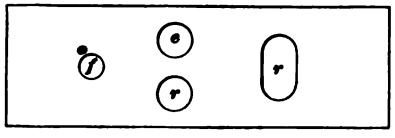

FIG. 11

middle of the valve. The movable parts of the valve consist of the triple piston *4*, the slide valve *3*, and the feed-valve *7*. The brake pipe is connected to passage *W*, and the brake cylinder is connected to passage *X*. Chamber *R* is in direct communication with the auxiliary-reservoir connection *Y*. The pressures in chambers *R* and *H* normally are equal. Reducing chamber *H*, or brake-pipe, pressure below chamber *R*, or auxiliary-reservoir, pressure will cause the auxiliary pressure to force the piston to the left until stopped by the stop *12* striking the head *10*.

Raising brake-pipe pressure above auxiliary pressure or reducing auxiliary pressure below brake-pipe pressure, as in bleeding a brake off, will cause the brake-pipe pressure to move the piston back toward the right to release position. It will thus be seen that the piston is made to move by making a difference of pressure on its two faces.

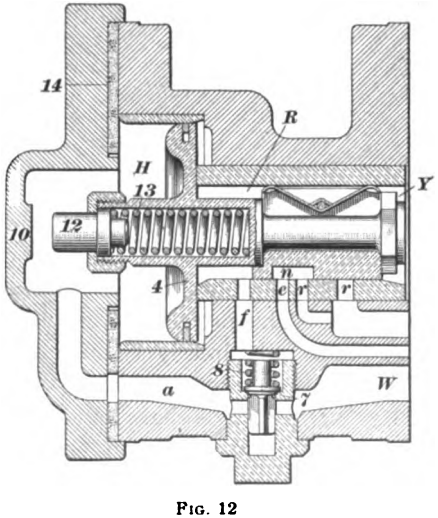

FIG. 12

As the slide valve *3* fits between the two shoulders of the stem of piston *4*, the valve must move with the piston.

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57. The face of the slide valve *3*, Fig. 9, is shown in Fig. 10. It contains only the cavity *n*. The slide-valve seat, Fig. 11, shows the location of the four ports it contains. The small port *r* is connected to the large brake-cylinder port *r*, Fig. 11, by a passage, as shown in the conventional view of the valve, Fig. 12. Port *e* is the exhaust port, and port *f* is the feed-port leading to the feed-valve.

58. When **charging the auxiliary reservoir,** the connections of the ports are as indicated in Fig. 12, in which the ports *e* and *r* and the cavity *n* in the slide valve are not shown in their actual relations, but are shown in such a way as to make the operation of the triple valve easier to understand.

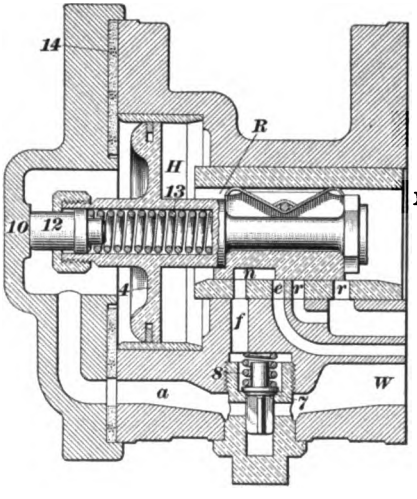

FIG. 13

In this figure, the movable parts are shown in the positions they occupy when the triple valve is in release position, which is its normal position. When the brake valve is placed in release position to release the brakes, the pressure in passage *a* and chamber *H* is raised above that of the auxiliary reservoir. This pressure forces the piston *4* to release position, Fig. 12, if not already there, and unseats the feed-valve *7*, allowing the brake-pipe air to flow through the valve *7* and the passage *f* into chamber *R* and the auxiliary until the brake-pipe and auxiliary pressures are about equal, when the spring *8* closes the valve *7* and holds it to its seat.

The port *f* is of such size that the auxiliary reservoir is quickly charged through it to brake-pipe pressure, and the two pressures then remain about equal. The pressure in the

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auxiliary is restored in 5 seconds after the release of a full-service application, so that the auxiliary is recharged by the time that the brake has fully released, and application after application can follow in quick succession without loss of brake power, provided the pump has sufficient capacity to maintain reservoir pressure.

59. To move the triple valve to **service position** and to make a service application of the brakes, a reduction is made in brake-pipe pressure. The auxiliary pressure then moves the piston from release position, Fig. 12, to service position, Fig. 13, closing both the exhaust port *e* and the feed-port *f*.

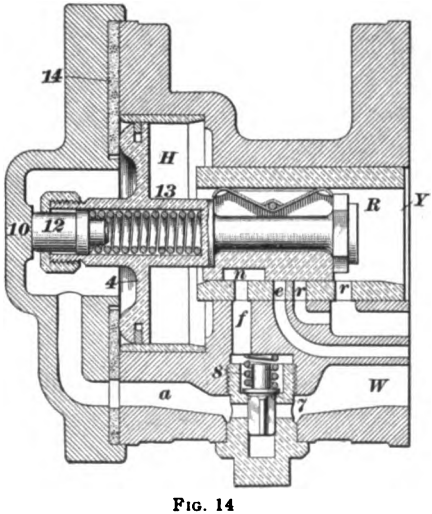

FIG. 14

In moving to service position, the stem *12* when it strikes the head *10* tends to stop the piston; but as all the force is not spent, the graduating spring *13* is compressed sufficiently to permit the valve to move forwards enough to open the right-hand port *r*. Auxiliary air then flows into the brake cylinder until its pressure has reduced to about brake-pipe pressure, when the graduating spring moves the piston and slide valve back until the port *r* is closed and the flow of air to the brake cylinder is stopped. This last position is called *service lap position*, or *lap position*.

The amount that port *r* will be opened during service application of the brakes depends on the rate at which the brake-pipe pressure is reduced. The opening must be large enough to permit auxiliary pressure to reduce at the same rate as brake-pipe pressure.

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60. To move the triple valve to **emergency position,** Fig. 14, and to cause an emergency application of the brakes, a sudden heavy reduction of brake-pipe pressure is made. This causes brake-pipe pressure to reduce so quickly that sufficient difference of pressure is obtained on the faces of the piston *4*, Fig. 14, to move the piston to the left with sufficient force to compress the graduating spring *13* until the piston bottoms on the gasket *14* and makes an air-tight joint with it. This movement first closes the exhaust port *e* and feed-port *f* and then opens port *r* wide, so that the auxiliary and the brake cylinder equalize their pressures almost instantly.

61. To move the triple valve to **release position** and to release the brake after it has been applied, either in service or emergency application, the brake-pipe pressure is raised above auxiliary pressure in order to force piston *4* to the right so that it will assume the position shown in Fig. 12. In this position, brake-cylinder air exhausts to the atmosphere through the brake-cylinder port *r*, the cavity *n* of the slide valve, and the exhaust port *e*. Also, the feed-valve *7* is forced open and brake-pipe pressure quickly equalizes with the auxiliary pressure through port *f* and chamber *R*.

62. To make a **graduated release** the brake valve should be moved alternately from release position to holding position. When this triple valve is used in connection with a motor-car brake equipment, its exhaust port *e*, instead of opening directly to the atmosphere at the triple valve, is piped to the brake valve. The holding position of the brake valve is the same as the release position, except that in the former position, the brake-cylinder exhaust pipe is closed and in the latter position it is open to the atmosphere. Consequently, when the brakes are released from the holding position of the brake valve, all triples move to release position, Fig. 12, and all brakes except the motor-car brake release. The brake valve prevents the escape of air from the motor-car brake cylinder, and to release that brake, the brake valve must be moved to release position. By moving the brake

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valve to release position for a few seconds and then back to holding position, part of the brake-cylinder pressure will be exhausted; consequently, by using the release and holding positions, the brake can be graduated off as desired.

63. Construction of the Feed-Valve.—The pump governor is usually set to permit of a 15-pound reduction in the main-reservoir pressure from the cutting-out pressure, before the governor again starts the compressor. The standard brake-pipe pressure recommended is 70 pounds. The cutting-in pressure of the governor that is recommended is

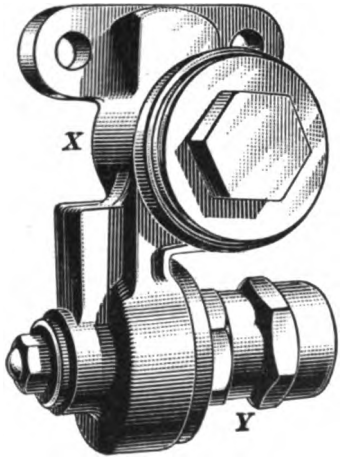

FIG. 15

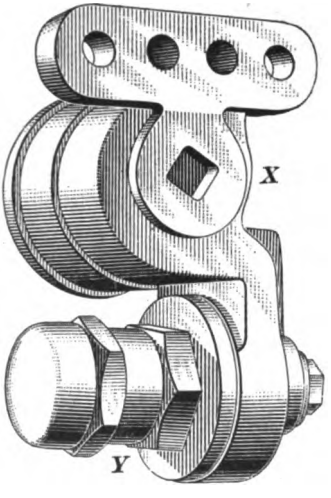

FIG. 16

15 pounds more, or 85 pounds, and the cutting-out pressure 100 pounds. The main-reservoir pressure therefore fluctuates through a range of 15 pounds, so that it cannot be connected directly to the brake pipe, as each fluctuation would apply and release the brake. The brake-pipe pressure must be maintained constant at the standard pressure—70 pounds—and it is the purpose of the feed-valve to do this. The feed-valve is connected in the main-reservoir pipe, as shown in Fig. 8, and all the air entering the brake-pipe must pass through it. It permits air to pass through it until the feed-

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valve pipe is charged to the pressure for which the feed-valve is adjusted to close, usually 70 pounds.

64. The external construction of the feed-valve is shown in Figs. 15 and 16, which illustrate the front and the back of the valve. The feed-valve consists of two parts: that at *X* contains the parts that govern the train-pipe supply of air from the main reservoir, and that at *Y*, the parts that control the operation of the valve in the part *X*:

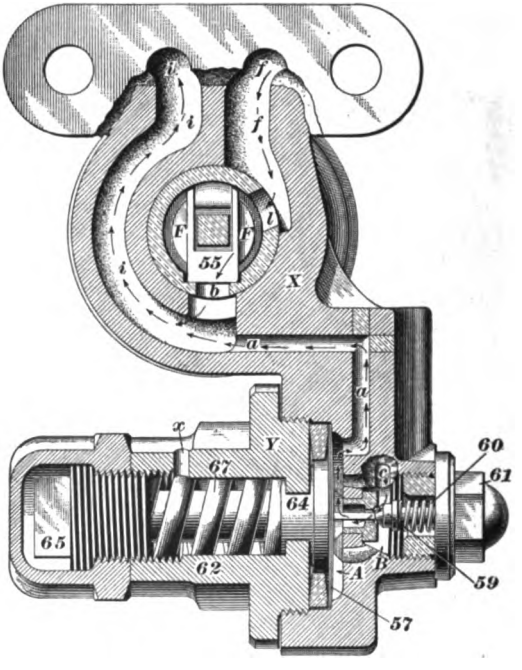

FIG. 17

65. In Fig. 17 is shown the back of the feed-valve, with part of the valve broken away so as to show the passages *a*, *f*, and *i* and their relation to ports *b* and *l*. When the feed-valve is in position in the piping system and the brake valve is in release and running position, the passage *f* is charged with air at main-reservoir pressure. Since port *l* in the supply-valve bushing connects passage *f* with chamber *F*—the

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space surrounding the supply valve *55*—it follows that chamber *F* is charged with main-reservoir pressure whenever passage *f* is so charged.

Passage *i* in the feed-valve is always in direct communication with the feed-valve pipe and is always charged with feed-valve pipe air. Furthermore, passage *i* is connected with chamber *F* through the supply port *b* in the supply-valve bushing. Passage *a* connects passage *i* with chamber *A*—the

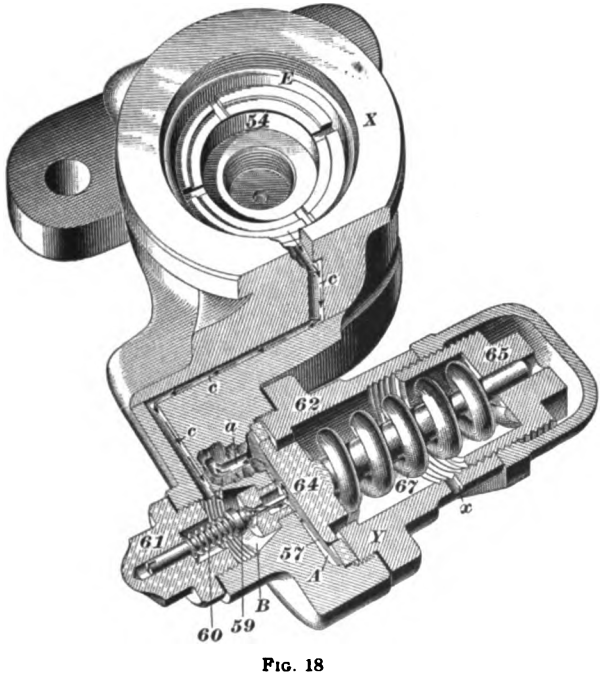

FIG. 18

space between the diaphragm *57* and the regulating valve *59*. Hence, chamber *A* is always charged with feed-valve pipe air, because it is in direct communication with that pipe.

The arrows indicate the flow of air from the main-reservoir passage *f* through the feed-valve to the passage *i* leading to the feed-valve pipe when the feed-valve is open and supplying air to the feed-valve pipe. A portion of the feed-valve has been broken away in such a manner as to show the regu-

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lating valve *59* and also how the end of the passage *c* opens into chamber *B*, the space surrounding the regulating valve.

66. In Fig. 18 is shown a perspective view of the feed-valve with the cap nut *53*, Fig. 19, removed and part of the valve, Fig. 18, broken away so as to show the course of the passage *c* and its relation to the regulating valve *59* and to the passage *a*. Passage *c* connects chamber *B* with chamber *E*—the space between the supply-valve piston *54* and the cap nut *53*—thus maintaining equal pressures in the two chambers. The regulating valve *59* controls communication between chambers *A* and *B*, so that when it is open, chamber *E* is in direct communication with the feed-valve pipe through the passage *c*, chamber *B*, valve *59*, chamber *A*, and passages *a*, Fig. 18, and *i*, Fig. 17. Another portion of the feed-valve shown in Fig. 18 is broken away so as to show how the end of passage *a* opens into chamber *A*.

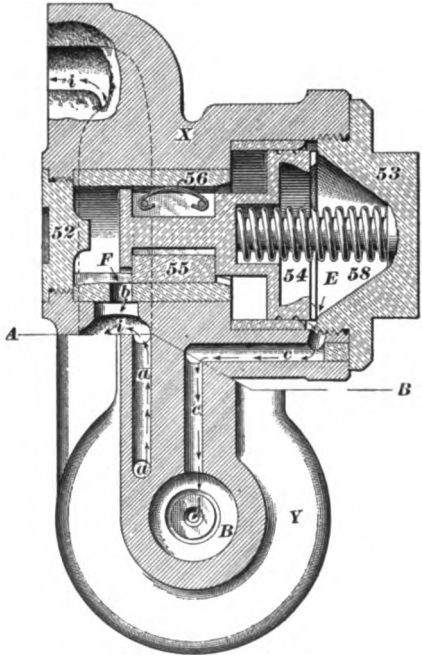

FIG. 19

67. In Fig. 19 is shown one side of the feed-valve attachment. The upper part *X* is sectioned through the middle so as to show the arrangement of the supply valve *55*, and the lower part *Y*, below the line *A B*, is sectioned in such a way as to show the passages *a* and *c* and chamber *B*. A portion of the upper part *X* of the valve is broken away so as to show the end of the passage *i*.

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The supply valve *55* controls the port *b* leading from chamber *F* into the passage *i*. This slide valve is operated by means of the supply-valve piston *54* and the supply-valve piston spring *58*. Although piston *54* makes a snug fit in its bushing, it is not provided with a packing ring for the reason that a certain amount of leakage from chamber *F* into chamber *E* is necessary in order that the feed-valve may work properly.

The spring *58* is made sufficiently strong to force the piston *54* and the supply valve *55* back against the flush nut *52* (which acts as a stop for the piston) whenever the difference in pressures in chambers *F* and *E* allows the spring to move the piston against the main-reservoir pressure. Port *b*, therefore, is closed when the pressure in chamber *E* is equal to that in chamber *F*. When the pressure in chamber *E* is less than that in chamber *F*, the greater pressure on the chamber *F* face of the piston *54* forces the piston forwards, moving the valve *55* with it and thus opening the port *b*. Therefore, the port *b* is always open when the pressure in chamber *E* is less than that in chamber *F*. The supply-valve spring *56* holds the supply valve *55* on its seat when that valve is relieved of pressure, and thus prevents dirt from getting between the valve and its seat. In Fig. 19, chamber *B* is shown with the regulating valve *59*, Fig. 17, removed.

68. Operation of the Feed-Valve.—As the parts *X* and *Y* are at right angles to each other, it is difficult to illustrate the operation of the feed-valve by means of true sectional views. For this reason, two conventional views, Figs. 20 and 21, have been prepared for use in explaining the operation of the feed-valve.

When the feed-valve is not under pressure, port *b* is closed and the regulating valve *59* is open. The spring *58* forces the supply valve *55* back until it covers the port *b*, as in Fig. 21, while the regulating spring *67* forces the diaphragm to unseat the regulating valve *59*, as in Fig. 20.

Fig. 20 shows the position of the parts of the feed-valve when the feed-valve pipe is charged to less than 70 pounds

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and air is feeding through the feed-valve into it. Under such conditions, main-reservoir air enters the passage *f* and chamber *F*, forcing the piston *54* forwards until it uncovers the port *b*. The air then flows from chamber *F* through the port *b* into the passage *i*, and thence into the feed-valve pipe, where it increases the pressure.

While the pressure of the feed-valve pipe is less than 70 pounds, the regulating valve *59* is held off its seat by the

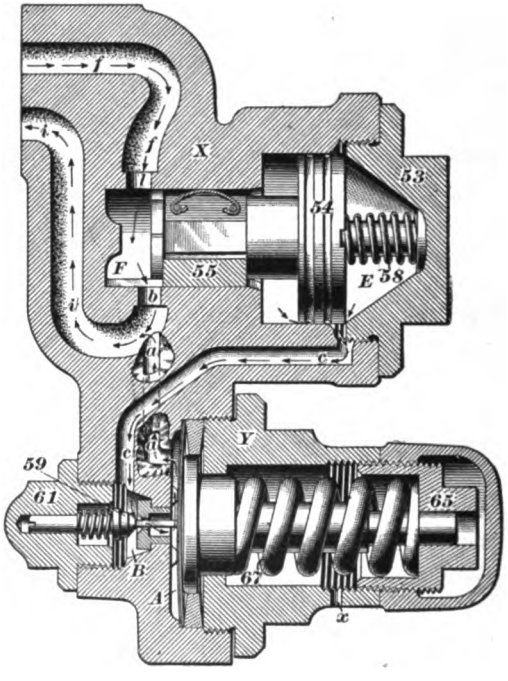

FIG. 20

regulating spring *67*, and there is direct communication between chamber *E* and the feed-valve pipe through the passage *c*, the valve *59*, and passages *a* and *i*. The leakage that takes place past the piston *54*, therefore, passes directly to the feed-valve pipe, as indicated by the arrows, so that chambers *E* and *A* are maintained at the pressure of the feed-valve pipe.

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When a pressure of 70 pounds is reached in the feed-valve pipe, the pressure on the diaphragm *57* is sufficient to compress the regulating spring *67* enough to allow the regulating valve *59* to close. This cuts off communication between chamber *E* and the feed-valve pipe, and the leakage occurring past the piston *54* then quickly charges chamber *E* to the same pressure as chamber *F*, which allows the spring *58* to move the supply valve *55* to its closed position, as shown in

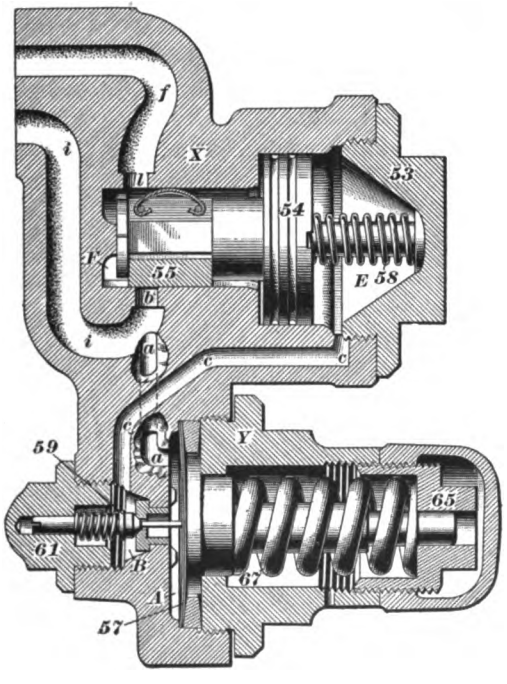

FIG. 21

Fig. 21. In this position no air can feed into the feed-valve pipe, because the port *b* is closed.

The parts of the feed-valve remain in the positions shown as long as the pressure of the feed-valve pipe remains at 70 pounds. Any reduction of pressure in this pipe, however, allows the spring *67* to expand and unseat the regulating valve *59*. Pressure in chamber *E* is then immediately reduced to the

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pressure of the feed-valve pipe, so that the greater pressure of air in chamber *F* forces the piston *54* to its open position, as shown in Fig. 20. The feed-valve pipe is then charged through the port *b*.

69. Regulation of the Feed-Valve.—If the feed-valve does not regulate the pressure of the feed-valve pipe properly, it can be made to do so by adjusting the regulating nut *65*. If the feed-valve maintains a pressure below the standard, it may be regulated by turning the regulating nut *65* slowly until the tension of the spring *67* is sufficiently increased. If the feed-valve maintains a pressure that is too high, the brake valve should be placed in service position and the brake-pipe pressure reduced 15 or 20 pounds below standard. After turning the regulating nut *65* so as to relieve the spring *67* of a little of its tension and placing the brake valve in release and running position, the pressure that is then maintained should be noted. If the pressure is still too high, it will be necessary to proceed again in the manner just explained and to continue regulating in this manner until the feed-valve is properly adjusted.

OPERATING THE BRAKE

70. Charging the Train. — When inspecting a train preparatory to charging the brake system, see that the first and the last cut-out cock in the brake pipe of the train are closed and that all the other cocks are open; also, see that the hose between cars are properly coupled up. Close the cut-out cock under all the brake valves except the one that the motorman is to use, and lap all the brake valves except the one that is to be operated. Also, close the signal-whistle cut-out cock at the rear end of the motor car and the cylinder-exhaust cock of the motor car. All the other cut-out cocks must be open on both the motor and the trailer cars.

If motor cars are to be handled as trailers, then the cylinder exhaust cock of all the trailer cars must be left open; but that

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of the motor car must be closed. Also, the compressors of all the trailer cars must be cut out by opening one of the compressor switches. The drain cocks on all the reservoirs must be closed. A cut-out cock is open when its handle is crosswise to the pipe; it is closed when the handle is parallel with the pipe.

When the train has been inspected properly, place the brake valve in release and running position and start the compressor by closing both snap switches in the electric circuit of the compressor. As both switches open the same circuit, opening either will stop the compressor motor. Therefore, both switches must be closed to start the motor.

71. Testing the Brake.— When the brake system is charged, note by the gauge the value at which the feed-valve maintains brake-pipe pressure; also, note the cutting-out pressure of the governor when the compressor stops. During the test, the cutting-in pressure also should be noted. After the brake system has been fully charged, as indicated by the governor stopping the compressor, make a 10-pound brake-pipe reduction from the motor car, to set the brakes, and then lap the brake valve. Pass toward the rear of the train and note whether or not all the brakes apply and that they do not leak off.

If a brake releases after being applied, it is possible that the cut-out cock under a brake valve is not closed, that the brake valve is not lapped, or that the rotary valve is leaking. There may be a leak from the auxiliary reservoir or its connections, the slide valve of the triple valve may be leaking, or the air may be leaking past the brake-cylinder packing leather, allowing the brake to leak off without the triple valve moving to release position.

If all brakes apply properly and remain on, then move the brake valve to release and running position and let it remain there. Pass along the train to the rear car and note all brake-cylinder push rods to see whether they have moved back to full release; also, note whether the brake shoes clear the wheels sufficiently to prevent dragging.

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If a brake that has not released is found, and it is on a motor-trailer car, note whether or not the cylinder-exhaust cock on that car is open; if so, the trouble may be in the triple valve, the feed-valve may not be open, or the brake rigging may be caught and thus prevented from moving to release position, although the brake-cylinder pressure may be exhausted. To find out whether this is the trouble, make a heavy application of the brakes and then release them, noting whether or not the air exhausts from the brake cylinder of the stuck brake; if it does, but the brake shoes do not leave the wheels, the rigging is stuck.

Occasionally, an emergency-application test should be made with both the brake valve and the conductor's valve, to make sure that the emergency application can be obtained if desired.

TRAIN CONTROL

72. Service Stops. — To make an application of the brake to control the train on a grade or to make an ordinary station stop, a train-pipe reduction should be made by placing the brake valve in service position. When the desired reduction is made, the handle should be moved to lap position and left there until the next reduction is necessary or until the brake is to be released. The power with which the brake is applied depends on the amount of the reduction. The greater the reduction, the greater will be the braking force until the auxiliary-reservoir and brake-cylinder pressures equalize. This equalization usually occurs with a 20-pound brake-pipe reduction from 70 pounds. Inasmuch as a further brake-pipe reduction cannot increase the brake-cylinder pressure after equalization has taken place, it follows that a further reduction would simply be a waste of air; besides, it would make the brakes release more slowly.

73. Although the braking force depends on the pressure in the brake cylinder, the effect of the braking force depends on the speed at which this force is applied. At high speeds, the brakes can be applied instantly and with full force without

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any unpleasant effect; but to make the same application at low speeds would bring the train to such a sudden stop as to throw the passengers out of their seats and perhaps injure them severely. The retarding force of the brake cylinder is practically constant at all speeds, but the moving energy of the train increases greatly with the speed. For example, a train moving at a speed of 20 miles per hour has four times as much energy to be destroyed by the brake in stopping as one traveling at a speed of 10 miles per hour; at 40 miles per hour, it has sixteen times as much energy as one moving 10 miles per hour. Consequently, the retardation of a train per second by a constant force would be only one-sixteenth as great at 40 miles per hour as at 10 miles.

74. Just how hard an application of the brakes should be made under given conditions and whether it should be made with one or with several reductions, depends on the speed, on whether a quick stop is desired, on the condition of the rail, and on the grade. These conditions vary so much that it is only by careful training that a motorman can become expert in the use of the brake.

In every case, the best stop will be made if the brakes are applied with as hard an application at the start as the conditions will permit and the brakes released from holding position as soon as the speed has been sufficiently reduced to make the retardation too fast for the comfort of the passengers on the train. The remainder of the stop can be made by graduating off the motor-car brake.

At high speeds, a heavy reduction should be made in order to get the greatest retardation while the momentum of the train is greatest. At moderate speeds, a lighter reduction is necessary. To make a smooth stop, therefore, make the reduction heavy enough to check the speed and soon enough so that if the brakes were held on until the train stopped, it would stop a car length short of the mark; then release the brakes from holding position when the speed is properly reduced and graduate the motor brake off to complete the stop. If the stop is on a grade, the motor-car brake must

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be kept on with sufficient pressure to hold the train stationary until the signal to go ahead is given, when the brake should be released before turning on the current.

75. Emergency Stops.—The emergency application of the brake should be made only to avoid an accident. It should be made without hesitation, regardless of the speed or the condition, by instantly throwing the brake-valve handle to emergency position and leaving it there. This will set the brake to its full power instantly and will stop the train in the shortest distance possible.

76. Unexpected Brake Applications.—If the brake applies without the aid of the motorman, he should immediately lap the brake valve. Lapping the valve will allow the train to come to rest as soon as possible; besides, it will prevent the loss of main-reservoir air, which will permit the brakes to be released promptly when the signal to go ahead is received.

The application of the brakes may be due to the opening of a conductor's valve, to a burst hose or a burst brake pipe, or to the train parting. If the conductor has set the brake, he will hold the conductor's valve open until the train has come to a stop, when he will close it. The motorman can then release the brakes as soon as he gets the signal. If a hose has burst, it should be replaced with an extra one; if there is none at hand, the hose from the front or the rear end of the train may be used. If the brake pipe has been ruptured so that the brakes back of the rupture cannot be used, the cut-out cock in the brake pipe just ahead of the rupture should be closed in order to cut out the brakes on the rear portion of the train. Next, the auxiliary reservoirs on the cars thus cut out should be drained and the drain cocks left open. The train may then proceed, and if necessary the hand-brakes on the cars having the air brakes cut out should be used.

If the break occurs in a branch pipe between the cut-out cock and the brake pipe, the procedure just outlined should be followed. Should the break occur between the cut-out cock

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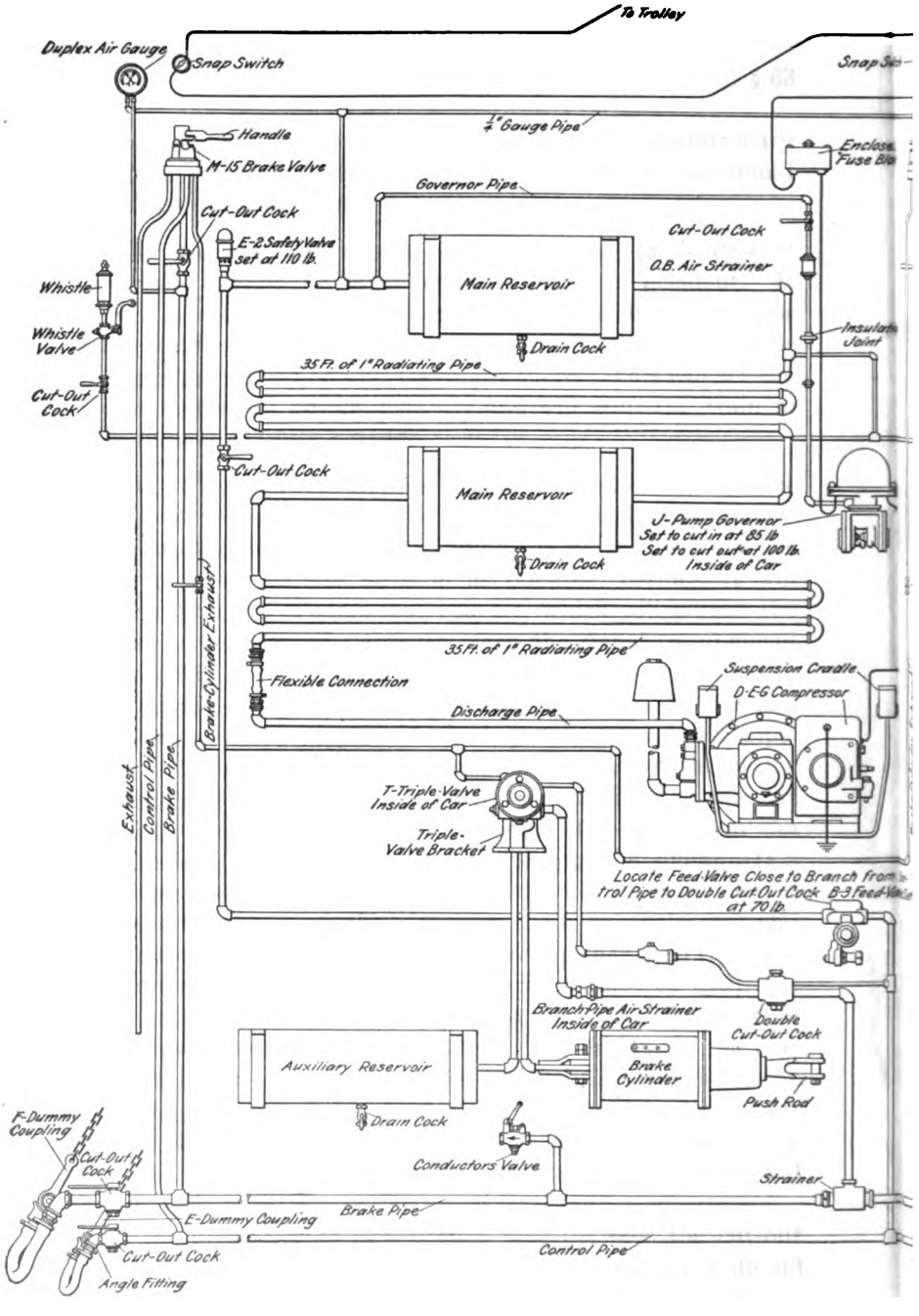

FIG.

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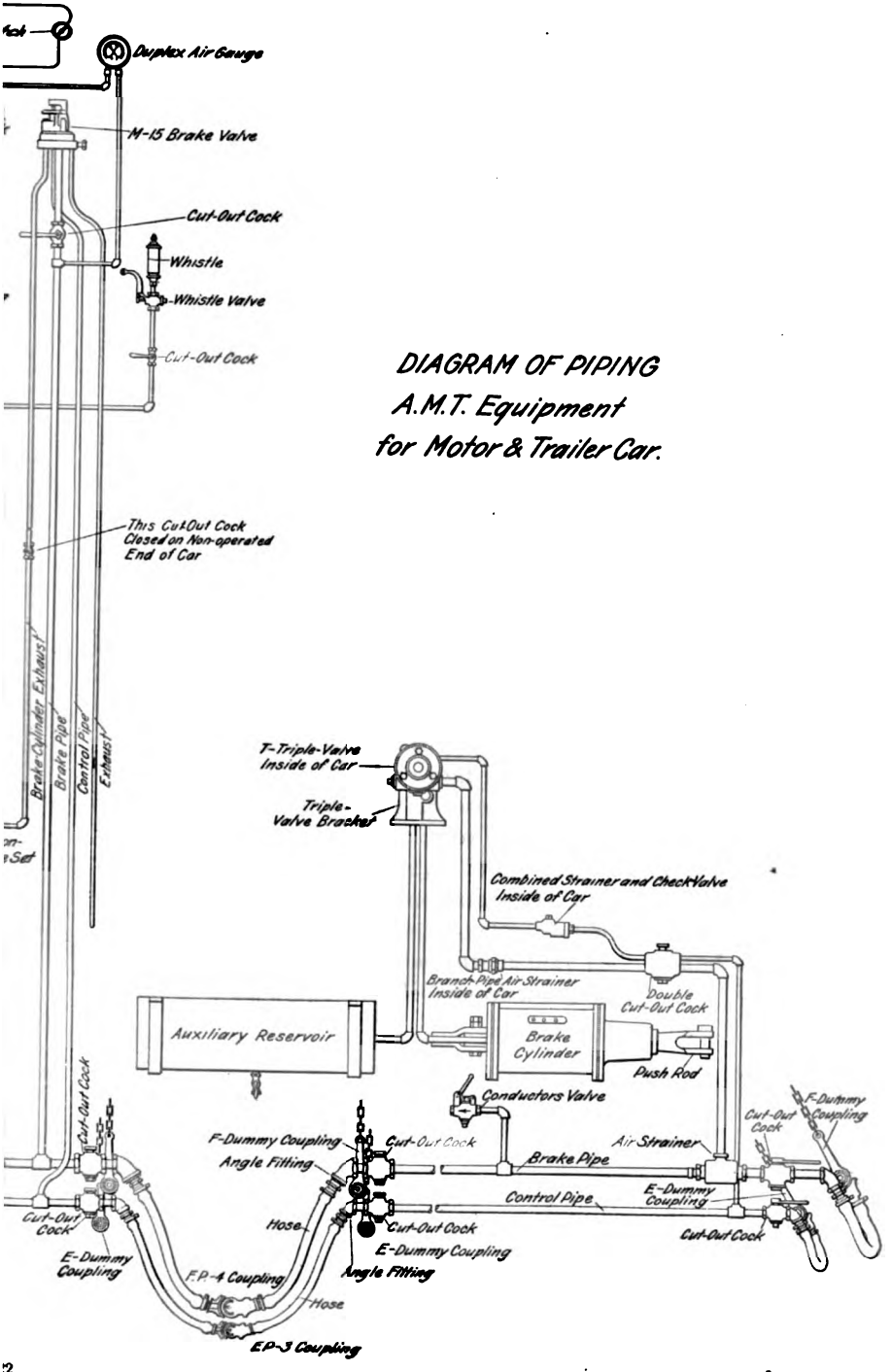
DIAGRAM OF PIPING
A.M.T. Equipment
for Motor & Trailer Car.



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and the triple valve, it will be necessary simply to close that cut-out cock and drain the auxiliary reservoir on that car.

77. Cutting Out a Brake.—A brake should never be cut out unless it is absolutely inoperative. It may be cut out by closing the cut-out cock in the branch pipe and opening the drain cock of the auxiliary reservoir and leaving this cock open.

78. Use of Sand.—If sand must be used when applying the brakes, it should be dropped on the rails for a train length before the brakes are applied, and should then be used continuously until the train has stopped or until the brakes are released. If some of the wheels are sliding, sand should not be dropped on the rails with the idea of starting them to roll. The sand will not start them, but will cause large flat spots to be worn in the wheels. If the wheels are found to be sliding, the brakes should be released sufficiently to permit them to revolve again; sand should then be used and the brakes reapplied.

79. Setting Out a Car.—In setting a car out of a train, first of all release the brakes; then close the angle cock on each side of the hose that is to be parted; then part the hose by hand and hang up properly in the dummy couplings the hose of the car that is to be set out. Before the car is left on the side track, the air brake should be released and the hand-brake applied (if necessary) to hold the car. The air brake should never be depended on to hold the car on a grade for any length of time, because it may leak off and allow the car to escape uncontrolled down the grade.

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ONE-CAR TO FIVE-CAR TRAIN SERVICE

PLAIN AUTOMATIC BRAKE WITH QUICK-RECHARGE, QUICK-SERVICE-APPLICATION, AND GRADUATED-RELEASE FEATURES

80. With the extension of the train service from three-car to five-car trains, the method of brake control must be one that is adapted to train operation in its full sense. Finer graduations of brake-cylinder pressure by the triple valve, a quick and more simultaneous service application of all the brakes, an extension of the graduated-release feature to all cars of the train, as well as the quick-recharge feature, must be included.

To fulfil the requirements of this particular service, the Westinghouse Traction Brake Company brought out their **A. M. T. brake equipment;** that is, their automatic motor equipment with type T triple valve.

81. Pipe Arrangement of the A. M. T. Equipment. The A. M. T. equipment for a motor car and a trailer car is shown diagrammatically in Fig. 22. Comparing Fig. 22 with Fig. 8, it will be seen that the system of piping is very similar. The feed-valve pipe of Fig. 8 is extended, as shown in Fig. 22, throughout the train, and it is called the *control pipe*. There are, therefore, two lines of pipes used in this equipment.

The brake pipe connects the brake valve to the triples throughout the train and provides a means whereby the motorman by manipulating the brake valve can operate the triples on each car to control the brakes; also, brake-pipe air assists the control pipe in recharging the auxiliaries after the release of the brakes.

The control pipe is always charged to feed-valve pressure, and it furnishes the air supply to the brake valve, as in the

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A. M. S. system. It provides a means of conveying to the brake valve that is being operated by the motorman a supply of air that is furnished from all the reservoirs on the train. It is connected with a passage in the brake-valve pipe bracket that opens into the space above the rotary valve; also, it is connected by means of a branch pipe to the triple valve of each car. Thus, the control pipe furnishes air through the brake valve to the brake pipe, and through the triple valves in order to assist the brake pipe in recharging the auxiliaries; also, it provides a means of graduating the release of the brakes on each car.

82. If all the cars in the train are equipped like the motor car, then it will not be necessary to make the control pipe continuous by means of hose connections between the cars. Each car will produce its own supply of air, and the compressors will have the work of compression fairly well distributed, because the greater part of the air supplied to the auxiliaries will be furnished from the main reservoir through the control pipe on each car. The compressor on the head car, however, will have the most work to do, as it not only has to maintain its own main-reservoir pressure, but also has to furnish some air to recharge the brake pipe and to assist in recharging the auxiliary reservoirs on the trailer cars.

83. The only difference between the apparatus used in the A. M. S. and the A. M. T. equipments is the type of brake valve and of triple valve. The added apparatus consists of the double cut-out cock in the branch pipe that leads to the brake pipe and the control pipe, and the combined strainer and check-valve in the control-pipe branch pipe.

In the A. M. T. equipment, as well as in the A. M. S. equipment, the exhaust port of the triple valve on the motor car is connected through the brake-cylinder exhaust pipe to the brake valve. This permits the brake on the motor car to be graduated off from holding position of the brake valve when the car is being operated singly or when it is desired to hold the motor-car brake on and to release the brakes on the other

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cars. The cut-out cock is open when the handle is crosswise to the pipe, and it is closed when it is parallel with the pipe.

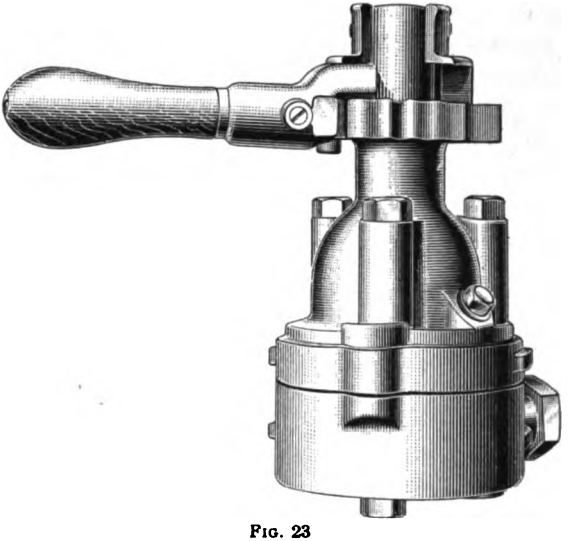

FIG. 23

84. Brake Valve.—The brake valve used with this system is the **M-15 type.** The exterior of the valve and its pipe bracket is shown in Fig. 23. The brake valve proper is mounted upon the pipe bracket, which forms the lowest section, or base, of the valve. All the pipe joints are made with the bracket. Therefore, the brake valve can be changed without disturbing the pipe joints. In order to insure against improper pipe connections with the pipe bracket, the bottom of the bracket has raised letters cast on it, as shown in Fig. 24. The letters *BP* stand for brake pipe; *BCEx* for brake-cylinder exhaust; *S*, for control pipe; and *Ex*, for brake-valve exhaust pipe.

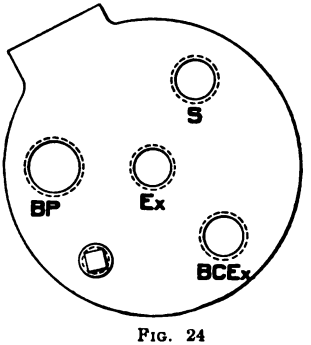

FIG. 24

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The brake valve has six positions of its handle, as indicated in Fig. 25, the handle, as shown, being in the release position.

85. The **release position,** in which the handle is normally carried, is used to release the brakes and recharge the brake pipe and auxiliaries. In release position, the brake valve connects the control pipe with the brake pipe, so that air from the control pipe can charge the brake pipe and maintain the pressures in the two pipes equal; also, the brake cylinder is connected with the atmosphere through the exhaust pipe, so that all brake-cylinder air can escape.

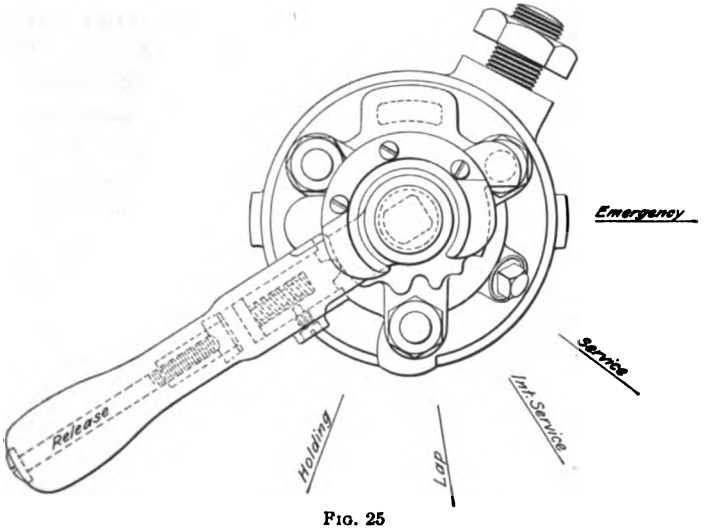

FIG. 25

86. The **holding position** is used when operating the car singly to graduate the brake off; also, in train operation, to hold the motor-car brake on while releasing the brakes on the other car. In this position, the brake valve connects the control pipe with the brake pipe, as in release position, thus charging the brake pipe to control-pipe pressure. Unlike in the release position, however, the brake valve blanks the port of the brake-cylinder exhaust pipe and holds the air in the brake cylinder.

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87. The **lap position** is used between reductions in order to hold the brakes applied. The brake valve blanks all ports except the brake-cylinder exhaust port. All the brake valves in the train except the one that is being operated must be left in lap position so as not to interfere with the proper operation of the brakes; consequently, the brake-cylinder exhaust port must be open to the atmosphere in the lap position of the brake valve in order to permit the trailer brakes to release when such operation is desired. To insure that the brake valves will be left in lap position, it is made the only position in which the handle can be removed.

88. The **intermediate-service position** is used when applying the brakes of a single car or those of a short train at low speeds. The brake valve, through relatively small ports, connects the brake pipe with the atmosphere, thus making a moderate reduction possible.

89. The **service position** is used on trains of considerable length and when running at high speeds. It connects the brake pipe to the atmosphere through considerably larger ports than those which are active when the intermediate position is used. Therefore, the reduction for the long train is made at about the same rate as the reduction for the shorter train, which is made through small ports.

Whether to use the intermediate or the service position under any given conditions depends on the judgment of the motorman. He will be governed by the length of the train and its speed; the condition of the rail, the grade, and the kind of stop desired. If the service position were used to stop a single car or a short train, it would reduce the brake-pipe pressure so quickly as to produce an emergency application of the brakes.

90. The **emergency position** is used to bring the train to a sudden stop. The service positions are capable of handling the train under ordinary conditions without discomfort to the passengers. In actual emergencies, however, safety is the important factor. Therefore, the emergency position,

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which will stop the train in the shortest distance possible, must be used. In this position a large port is opened between the brake pipe and the atmosphere and brake-pipe pressure quickly drops to zero, thus actuating the triple valve and setting the brake with its maximum power.

91. Conductor's Valve.—A valve called the **conductor's valve,** Fig. 26, is located at some convenient point in each car, generally with a cord attached to the handle *9*. This cord runs the entire length of the car, so that the valve can be operated from any location on the car. This valve is to be used by the conductor to stop the train, but only in the event of an actual emergency of which the motorman is unaware.

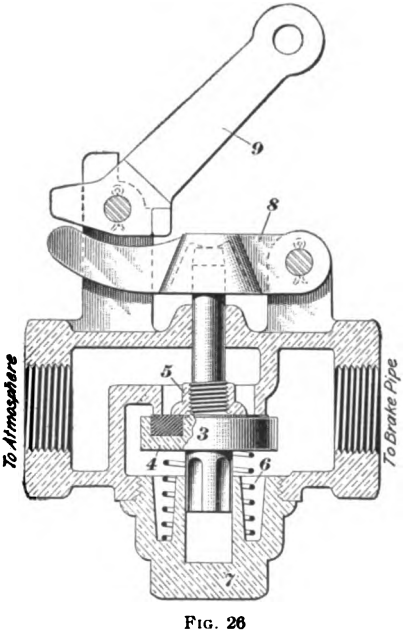

FIG. 26

Pulling the cord causes the handle *9* to move the end of the lever *8* downwards and to unseat the check-valve *3*. This allows brake-pipe pressure to escape quickly to the atmosphere and produces an emergency application of the brake. When this valve is once opened, it must be held open until the train stops, after which it should be closed.

92. Type T Triple Valve.—A sectional view of the **T-2 triple valve** with the parts in release position, is shown in Fig. 27. This valve consists of a plain triple with a graduating valve operating on top of the slide valve. Besides applying and releasing the brakes, like the ordinary plain triple, this valve has also quick-recharge, quick-service-application, and graduated-release features that make it

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peculiarly adapted to the class of service now under discussion. The triple valve has connections with the brake pipe, the control pipe, the auxiliary reservoir, the brake cylinder, and the exhaust pipe.

The graduating valve *7* is made to fit between the shoulders of the stem of the piston *4* that operates it, so that its movement begins and ends with the movement of the piston *4*. The slide valve *3*, on the other hand, is shorter than the distance between the shoulders that operate it. Therefore, at the beginning of the movement of the piston *4*, either to the

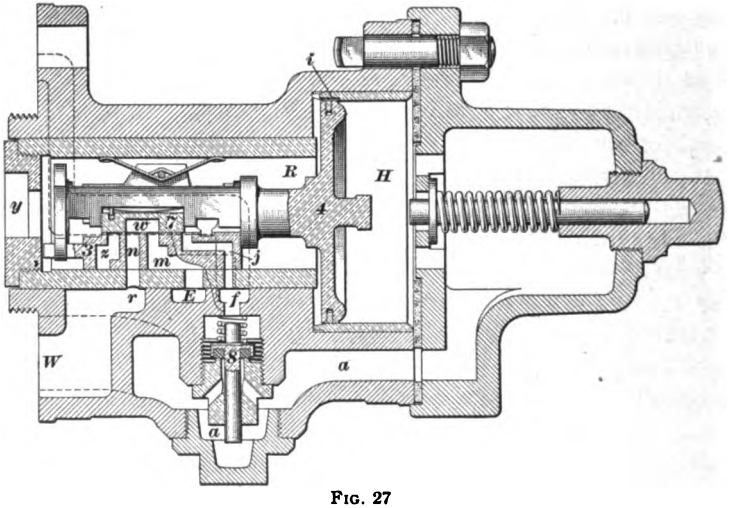

FIG. 27

right or to the left, the graduating valve is moved a distance equal to the play between the slide valve and the shoulder of the stem before the slide valve is moved. When the shoulder of the stem strikes the slide valve, both valves move together with the piston *4*. The ports, passages, etc. in Fig. 27 are lettered and numbered the same as those in Figs. 32, 33, and 34.

93. The graduating valve, and the slide valve and its seat of the T type triple valve are shown in Figs. 28 to 31, inclusive.

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The graduating valve, Fig. 28, has a small cavity v and a large cavity w.

The slide valve, Figs. 29 and 30, is faced at both the top and the bottom. The bottom face, Fig. 30, fits the valve seat,

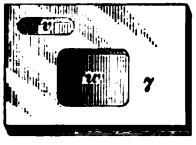

FIG. 28

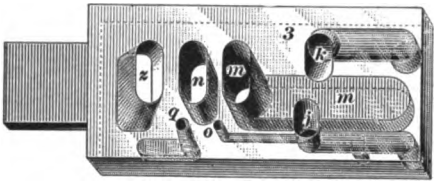

FIG. 29

Fig. 31, and the top face, Fig. 29, acts as the valve seat for the graduating valve.

Cavity v, Fig. 28, controls ports q and o, Fig. 29, and cavity w, Fig. 28, controls ports n and m, Fig. 29. The slide valve has seven ports in all, and they pass through the valve from face to face.

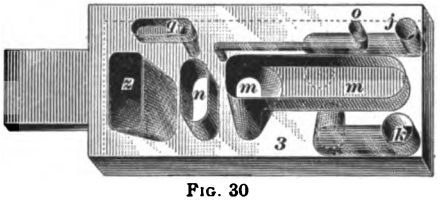

FIG. 30

When explaining the operation of the triple valve, conventional views instead of true sectional views will be used, because they can be understood more readily.

94. The parts of the triple valve are forced by the air pressure of the brake pipe to **charging position** and **release**

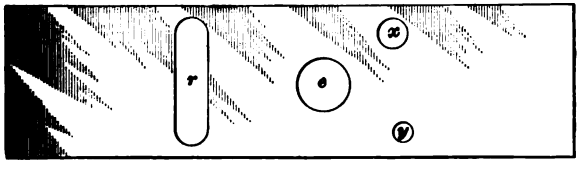

FIG. 31

position when the brake valve is moved to release position. The triple valve then allows the brake pipe and the auxiliary reservoir to be charged. A conventional view of the triple

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valve in release position is shown in Fig. 32. The brake-pipe connection is at *W*, the control-pipe connection at *C*, the brake-cylinder connection at *X*, the triple-exhaust-pipe connection at *E*, and the auxiliary-reservoir connection at *Y*.

When charging the auxiliary reservoir, brake-pipe pressure enters at *W* and passes through passage *a*, chamber *H*, feed groove *i*, and chamber *R* into the auxiliary. Also, it raises feed-valve *8* and passes through feed-ports *f*, *j*, and *u*, chamber *R*, and on to the auxiliary.

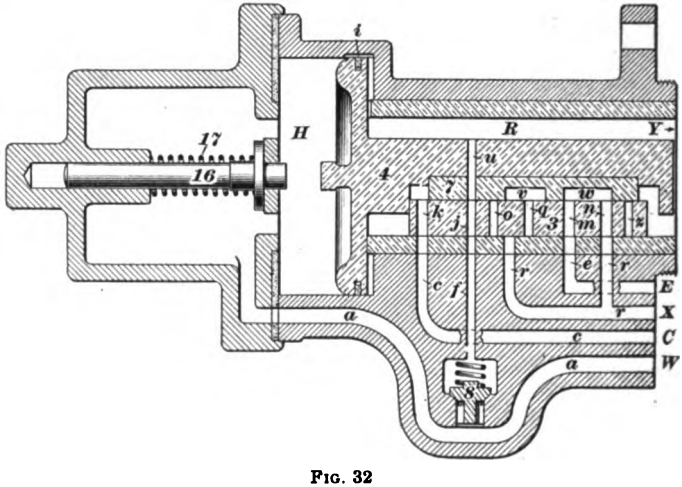

FIG. 32

The feed-valve check-valve *8* prevents auxiliary-reservoir air from flowing back into the brake pipe in case brake-pipe pressure is reduced below auxiliary-reservoir pressure.

Control-pipe pressure also assists in charging the auxiliary. Air passes through passage *c*, port *k*, and chamber *R* into the auxiliary. The feed-groove *i* is a small half circle, and the area of the port *j* is only half that of port *k*; therefore, the control pipe really furnishes more air in charging or in recharging the auxiliary than does the brake pipe.

95. The three channels for simultaneously supplying air to the auxiliary constitutes the quick-recharge feature of the triple valve. Their area is such that after an application of

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the brake they will, after release, recharge the auxiliary reservoir in the interval of time required for brake-cylinder air to exhaust to the atmosphere, thus providing maximum braking force no matter how quickly one application follows another.

In this position also, the brake cylinder is open to the atmosphere through passage *r*, port *n*, in slide valve *3*, cavity *w* in the graduating valve, ports *m* and *e*, and exhaust-pipe connection *E*.

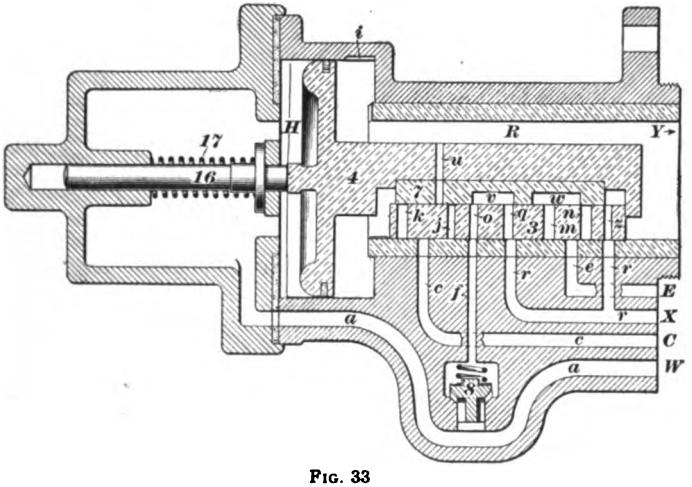

FIG. 33

96. A conventional view of the triple valve in **service-application position** is shown in Fig. 33. If a brake-pipe reduction of several pounds occurs when setting the brake, piston *4* will move forwards, closing the feed groove *i*. As the piston continues its movement, the graduating valve first closes the feed-port *j* and then the control port *k*. The shoulder of the piston stem then engages the slide valve and moves the valve forwards until the piston is stopped by the graduating stem *16* and spring *17*. The parts are then in service-application position. Air from the auxiliary reservoir flows into the brake cylinder through ports *z* and *r*. At the same time, brake-pipe air, being at a higher pressure than brake-cylinder air, raises feed-valve *8* and passes into the brake cylinder through ports *f* and *o*, cavity *v*, and ports *q*

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and *r*. This creates a local brake-pipe reduction at each triple valve that quickens the service application of the brakes and constitutes the quick-service application feature of the triple valve.

The relative size of ports *o* and *z*, which limit the flow from the brake pipe and the auxiliary reservoir into the brake cylinder, is shown in Fig. 29. The relative capacities of these ports is such that the auxiliary pressure will reduce much faster through port *z* than will brake-pipe pressure through port *o*.

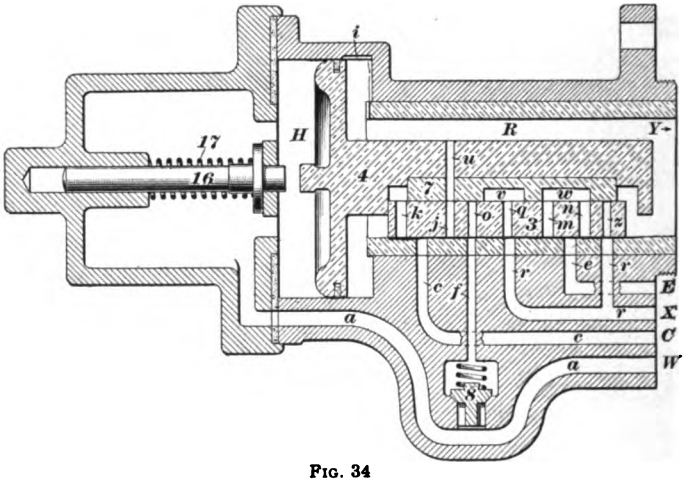

FIG. 34

97. The **service-lap position** of the triple valve is shown conventionally in Fig. 34. When auxiliary pressure is reduced slightly below brake-pipe pressure, piston *4* will move backwards until the shoulder on the stem engages the slide valve, when it will be stopped by the valve. The parts are then in service-lap position. The graduating valve has closed both ports *o* and *z* and stopped the flow of air into the brake cylinder.

If another reduction of several pounds is made, the piston *4* will again move to service position and will remain there until auxiliary pressure has reduced slightly below brake-pipe pressure, when the piston will return to service-lap position, and so on for each reduction up to the point where auxiliary-

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reservoir and brake-cylinder pressures equalize. Any further reduction of brake-pipe air will only be a waste, as no more brake-cylinder pressure will result.

98. The **release position** of the triple valve is shown conventionally in Fig. 32. Raising brake-pipe pressure forces piston *4* from service-lap position to release position. The pressure in the brake cylinder escapes through ports *r* and *n*, cavity *w*, and ports *m* and *e* to the atmosphere, releasing the brake at the same time that the auxiliary recharges, as explained in the instruction on charging position.

99. The **graduated-release feature** of the triple valve is placed in service by the proper manipulation of the brake valve. If the brake valve is moved to release position and left there, the brake pipe will recharge faster than will the auxiliaries, and the triple piston will be held in release position by the greater brake-pipe pressure, thus releasing the brake completely.

If, however, the brake valve is placed in release position only long enough to raise brake-pipe pressure a few pounds, and is then returned to lap position, the triple piston will at first be forced to release position. The auxiliary and brake pipe will quickly equalize under these conditions, and the continuous flow of control-pipe air into the auxiliary will raise the pressure there above brake-pipe pressure sufficiently to move the piston, slide valve, and graduating valve to service-lap position, Fig. 34.

Raising brake-pipe pressure a few pounds will again force the triple piston to release position, after which it will return again to service-lap position, as already described. This operation can be repeated until the brake pipe is nearly fully recharged, the reduction of brake-cylinder pressure each time depending on the amount the brake-pipe pressure is increased. This operation constitutes the graduated-release feature of the triple valve.

100. **Double Cut-Out Cock.** — It is very important that both the brake-pipe and the control-pipe branches leading

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to the triple valve be either open or closed. Under no circumstances should one pipe be open and the other closed, as might happen if each had its separate cut-out cock. The cut-out cock used to accomplish this double action is shown in cross-section in Fig. 35. It is an ordinary cut-out cock, except that it has two separate passages through both the body *2* and the valve *3*. The upper passage is for the control-pipe connection and the other one for the brake-pipe connection. Turning the handle parallel with the pipe will close both ports, and turning it crosswise to the pipe will open both ports. The double cut-out cock on a car should be closed only when the brake on that car is in such condition that the brake must be cut out.

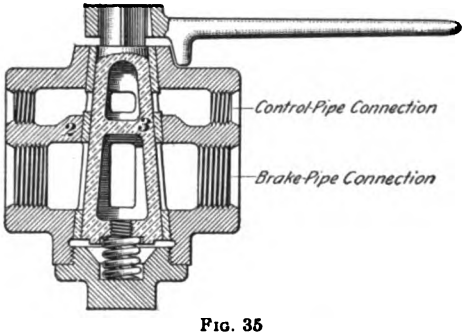

FIG. 35

101. Combined Air Strainer and Check-Valve. The **combined air strainer and check-valve** used in the branch pipe of the control pipe is shown in section in Fig. 36. The strainers *7* and the curled hair *a* between them prevent foreign matter that might cut the valve faces and clog the ports from being carried into the triple valve. The check-valve allows control-pipe air to enter the triple valve, but prevents auxiliary air

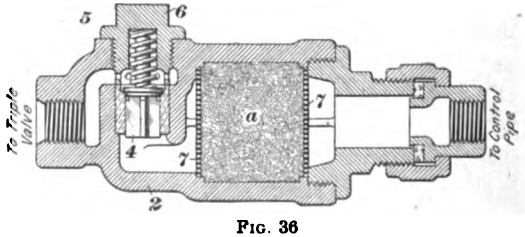

FIG. 36

from escaping through the control pipe to the atmosphere in the event of the control pipe becoming ruptured from any cause.

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BRAKES
(PART 2)

ONE-CAR TO FIVE-CAR TRAIN SERVICE
(Continued)

AUTOMATIC BRAKE WITH QUICK-RECHARGE, QUICK-SERVICE-APPLICATION, GRADUATED-RELEASE, AND HIGH-EMERGENCY BRAKE-PRESSURE FEATURES

CONSTRUCTION OF THE BRAKE

1. As the train service of electrically operated vehicles was perfected, it grew in favor, and eventually it was applied to urban and interurban service between cities located a considerable distance apart. In order to meet fully the two opposing conditions of high-speed long-distance runs between cities and the frequent stops and flexibility required in the city service, it was found that in addition to the four distinctive features of the A. M. T. system, another feature of the brake system had to be added.

For the easy, smooth, and safe control of the train in city service, moderate brake-cylinder pressures for moderate reductions, means of graduating both the application and the release of the brakes, and quick-recharging features are required. For the high-speed running between cities, however, it is necessary to provide some means of stopping the train in the shortest distance possible in case of an emergency. This increased emergency brake-cylinder pressure is the new

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feature that, together with the four features of the A. M. T. equipment, forms what the Westinghouse Traction Company call their **A. M. M. system,** which is intended for use on trains of five cars or less. The *M triple*, which forms a part of this equipment, is used very extensively throughout the country in elevated, subway, and interurban systems.

2. Pipe Arrangement of the A. M. M. Equipment. The A. M. M. equipment for a motor car and a trailer car is shown in Fig. 1. By comparing this equipment with the A. M. T. equipment described in *Brakes*, Part 1, it will be seen that practically the only difference between them is that a different type of triple valve is used. The T triple is not fastened directly to the brake cylinder as is the M triple, but is fastened to a bracket inside the car. It is recommended, however, that the M triple be placed inside the car whenever practicable, as this will greatly increase its life and satisfactory operation.

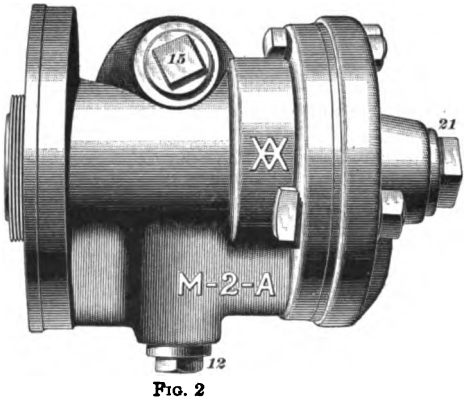

FIG. 2

3. Type M Triple Valve.—An illustration of the outside of the type M triple valve is shown in Fig. 2. The interior construction of this valve is illustrated by the two sectional views shown in Fig. 3, view (*a*) being a vertical section lengthwise through the center of the valve, and view (*b*) a vertical section crosswise through the middle of the cap nut *15*, Fig. 2, showing the by-pass piston and the by-pass valve. The parts of the triple valve, Fig. 3, are: *2*, valve body; *3*, slide valve; *4*, piston; *7*, graduating valve; *9*, check-valve; *10*, rubber seat of check-valve; *11*, check-valve spring; *12*, check-valve cap nut; *13*, by-pass piston; *15*, by-pass piston cap nut; *16*, by-pass valve; *17*, rubber seat; *18*, by-pass cap nut; *19*,

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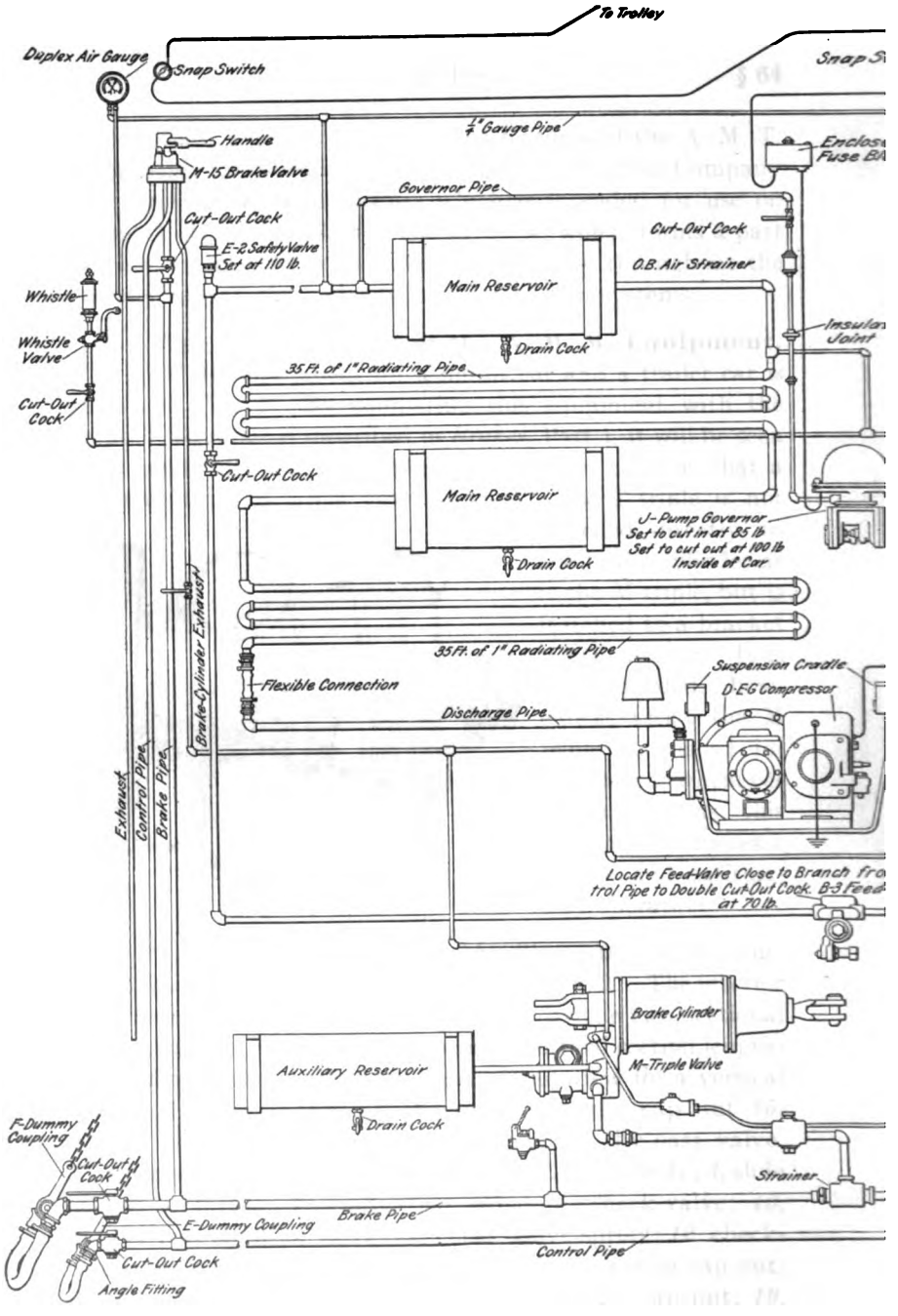

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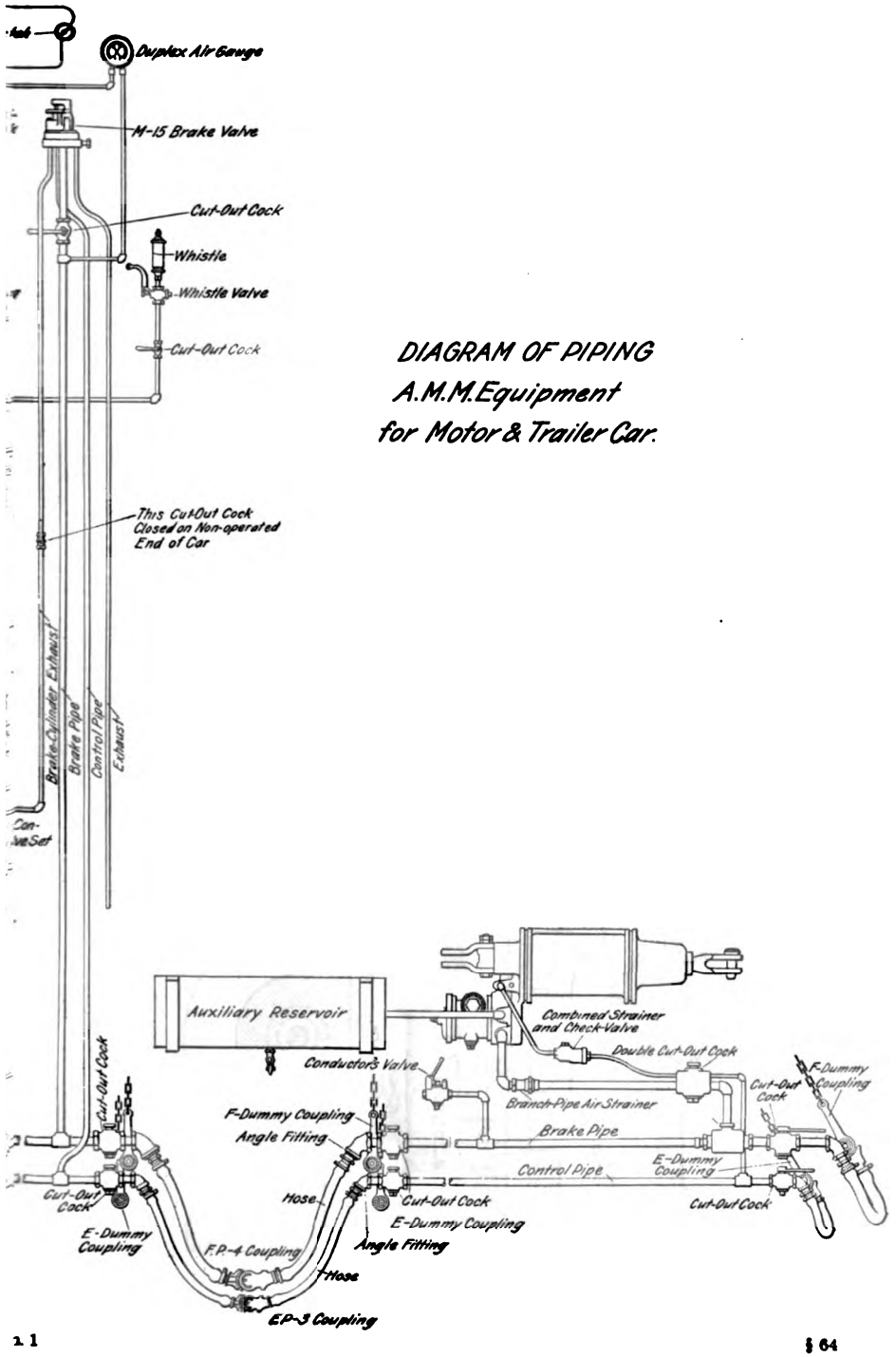
DIAGRAM OF PIPING
A.M.M. Equipment
for Motor & Trailer Car.



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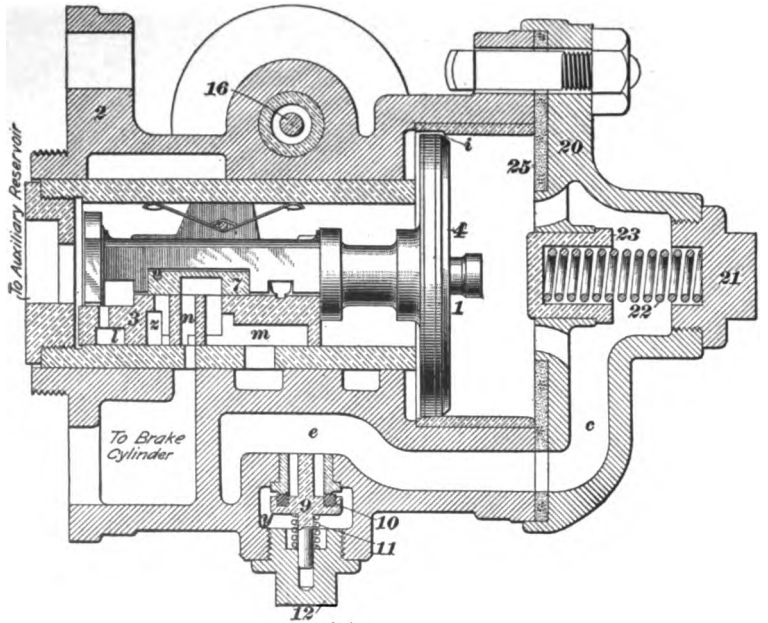
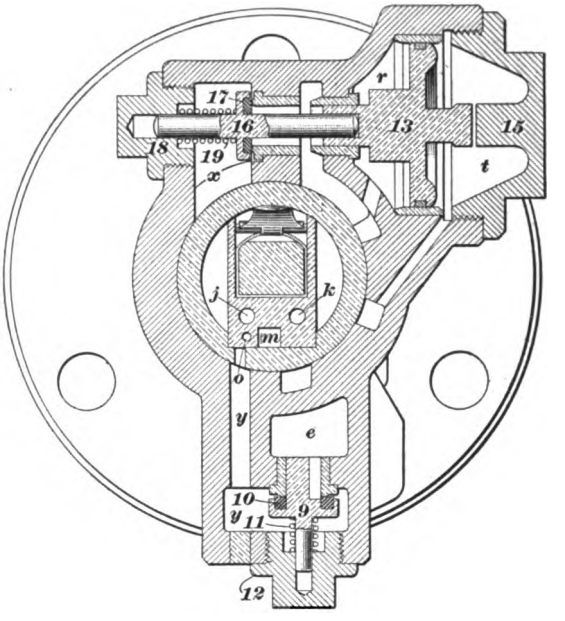


(a)



(b)

FIG. 3

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by-pass valve spring; *20*, cylinder cap; *21*, graduating nut; *22*, graduating spring; *23*, graduating sleeve; and *25*, cylinder-cap gasket.

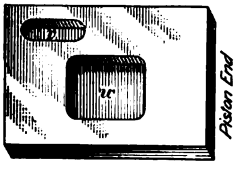

FIG. 4

4. The graduating valve, the slide valve, and the slide-valve seat are shown in Figs. 4 to 7, inclusive. The graduating valve is the same as that in the T triple, *Brakes*, Part 1. Fig. 5 illustrates the top of the slide valve, which is the seat for the graduating valve, and Fig. 6 the bottom of the slide valve. Besides the seven ports of the T triple valve, the M triple slide valve has two extra ports *l* and *s*, Figs. 5 and 6.

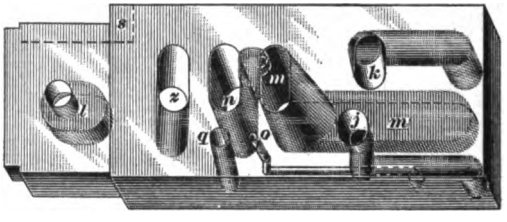

FIG. 5

The valve seats of the T triple and the M triple differ in that the M triple has two extra ports, namely, the port *t* and the small port *r*. The port *t*, Fig. 7, leads to the outer face of the by-pass piston *13*, Fig. 3 (*b*), and is used only in the emergency

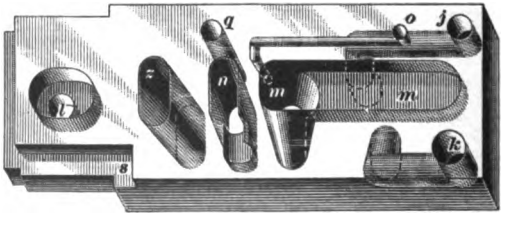

FIG. 6

position of the slide valve. The small port *r*, Fig. 7, connects with the large port *r*; also, it leads to the chamber back of the inner face of the by-pass piston *13*, Fig. 3 (*b*). It is con-

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nected with port *x*, Fig. 7, which leads to the control pipe, through the by-pass valve *16*, Fig. 3 (*b*). This valve, when

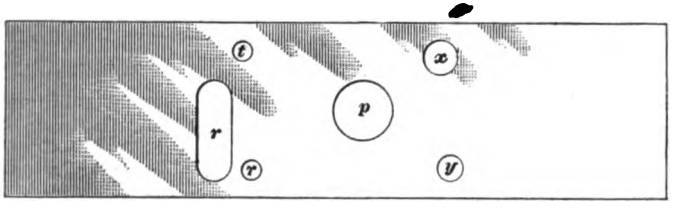

FIG. 7

opened in emergency position, admits control-pipe air into the brake cylinder through port *x*, valve *16*, and port *r*.

5. Figs. 2 to 7, which have just been considered, indicate the true location of the ports, passages, and parts of the M triple valve; but, in order to show their purpose more clearly, it will be necessary to resort to conventional illustrations. In the conventional illustrations of this valve, Figs. 8 to 13, inclusive, the true proportions of these ports, etc., as well as their relative positions, are entirely disregarded. For

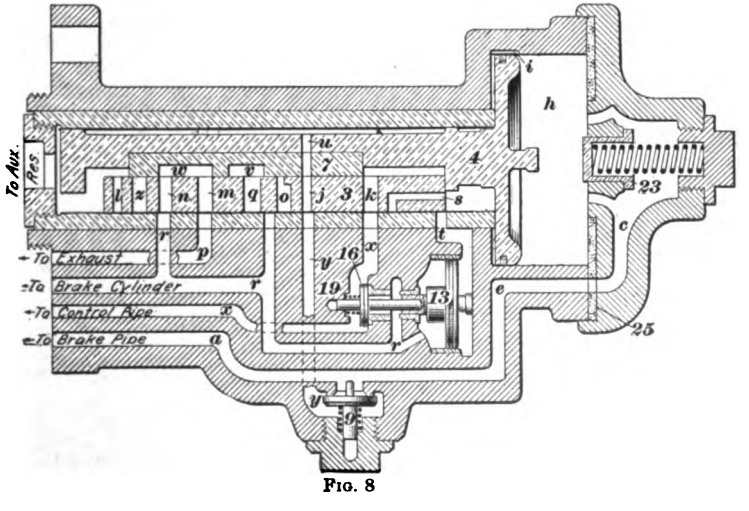

FIG. 8

example, the true location of port *s*, Fig. 6, is at the end of the slide valve farthest from the piston end, whereas, in the con-

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ventional views, it is located at the piston end of the slide-valve.

6. When the brake valve is placed in release position to charge the train, the brake pipe is charged, the triple valve is moved to **charging-and-release position,** Fig. 8, and brake-pipe air enters the triple through passage *a*. This air then flows through passages *e* and *c*, chamber *h*, and feed groove *i* to the auxiliary reservoir. At the same time, the air unseats the check-valve *9* and passes through *y*, *j*, and *u* into the auxiliary reservoir. Thus, brake-pipe air enters the

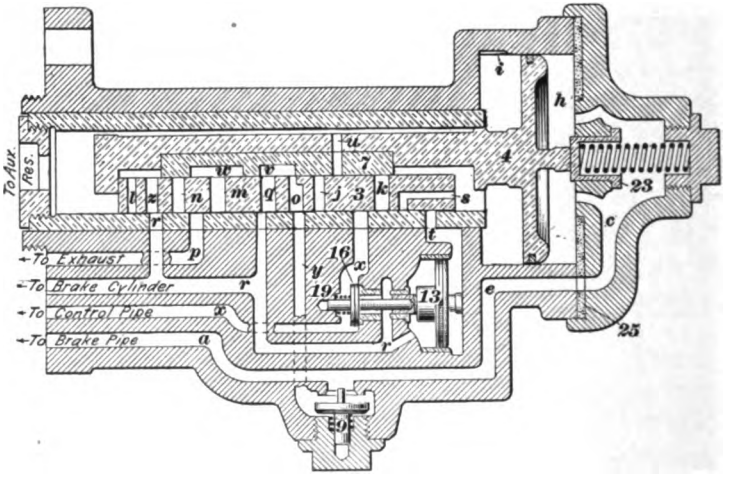

FIG. 9

auxiliary through two paths. Control-pipe air enters the triple through the passage *x*, and passes through port *k* of the slide valve into the auxiliary. These three paths for charging the auxiliary reservoir constitute the *quick-charging feature* of the valve. The auxiliary is recharged at about the rate that the brake cylinder discharges after a release, so that by the time the brake is fully released the auxiliary is fully recharged.

7. When the brake valve is placed in intermediate-service position, the triple valve is moved to **quick-service posi-**

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tion, Fig. 9. The service reduction of the brake-pipe pressure causes auxiliary pressure to force the piston *4* forwards until it strikes the graduating sleeve *23* and is stopped. The first part of the movement of piston *4* closes feed groove *i* and moves the graduating valve *7* until it closes the ports *n*, *j*, and *k*, thus shutting off all communication between the brake pipe and the auxiliary reservoir, the control pipe and the auxiliary reservoir, and the brake cylinder and the atmosphere. This same movement of the graduating valve also uncovers port *z*, while the cavity *v* of the graduating valve connects ports *q* and *o*.

As the piston *4* moves forwards, the shoulder on the piston stem engages the slide valve *3* and moves it to quick-service position. In this position, the port *z* of the slide valve *3* registers with the port *r* of the seat, permitting auxiliary air to flow into the brake cylinder and apply the brakes. At the same time, the small port *r*, port *q*, cavity *v*, port *o*, and passage *y* connect the chamber below the check-valve *9* to the brake cylinder, reducing the pressure below the valve and allowing brake-pipe pressure to open the valve and air from the brake pipe to flow into the brake cylinder, in this way producing a local reduction in the brake-pipe pressure at the triple valve. This constitutes the *quick-service feature* of the M triple valve. Each triple causes a slight local reduction in the brake-pipe pressure, and the effect of this reduction is quickly transmitted from car to car throughout the train, thus considerably shortening the interval between the application of the first brake and last one. The amount of this local reduction is not great, because the ports *r*, *q*, and *o* are small; also, because port *q* is restricted by the slide valve as the valve approaches full-service position, and is entirely closed before the service port *z* is fully open.

8. The amount that the port *q*, Fig. 9, is opened for any reduction depends on the rate at which brake-pipe pressure reduces, as compared with auxiliary pressure. With a short train, the brake-pipe reduction is sufficiently rapid to cause a difference in pressure that is great enough to cause the

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auxiliary pressure to force piston *4* at once to **full-service position,** Fig. 10, thus blanking the small port *r* and cutting out the quick-service feature, which in this position is not needed. Port *z* is now open wide, but port *q* is closed and no brake-pipe air can flow into the brake cylinder. Whenever the brake-pipe reduction is so rapid that the quick-service feature is not needed, the triple valve will go to full-service position, as just explained, and cut out the quick-service feature. On the other hand, when the reduction is slower, as on long trains, or when only a moderate service

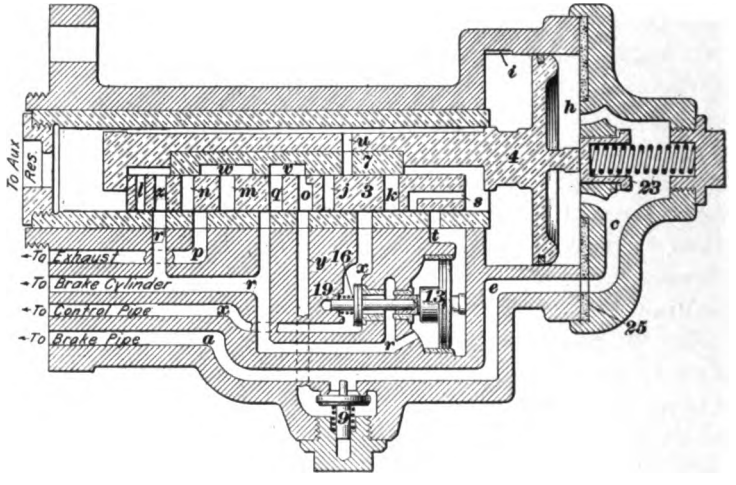

FIG. 10

reduction is made, the quick-action feature is not cut out. Under such circumstances, a partial opening of the service port *z* is sufficient to equalize the auxiliary and brake-pipe pressures quickly; besides, great enough difference in pressure cannot be obtained to compress the graduating spring. Thus, the triple cannot assume full-service position and thereby close the quick-service port *q*.

The quick-service ports *o* and *q* are smaller than the service port *z*, Fig. 5; thus, the flow of brake-pipe air is retarded and an emergency application is prevented when only a service application is intended. Also, because of the rapid flow of

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air from the auxiliary reservoir to the brake cylinder through the comparatively large port *z*, Fig. 10, and the consequent reduction of pressure on the auxiliary-reservoir face of piston *4*, the piston and the graduating valve are moved to the left and port *q* is closed. The brake-pipe reduction is thus cut off at the triple valve after the reduction has stopped at the brake valve.

9. When the brake valve is lapped, the triple is moved to **service-lap position,** Fig. 11. The movable parts of the

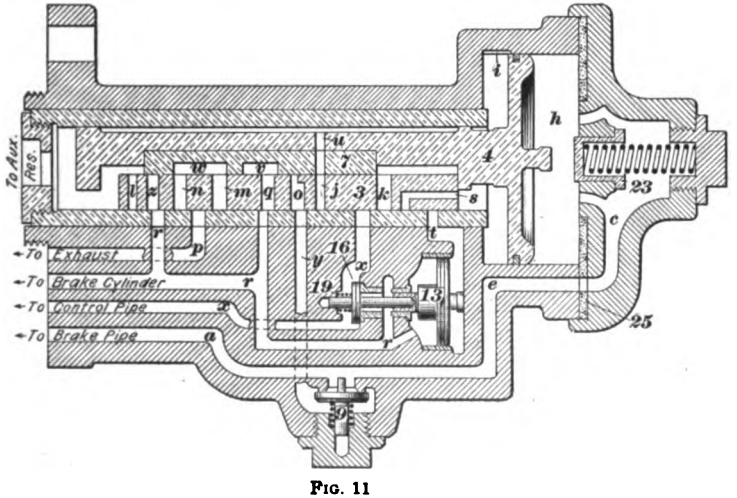

FIG. 11

triple assume this position between reductions made during an application of the brakes.

After the desired reduction is made during an application of the brakes, the brake valve is lapped and thus stops further brake-pipe reduction. The auxiliary pressure continues to reduce until it is slightly below brake-pipe pressure, when the piston *4* and the graduating valve are moved by brake-pipe pressure to service-lap position. While this difference in pressure is sufficient to move the piston and graduating valve, it is not great enough to move the slide valve *3* when the shoulder of the piston stem engages the valve; consequently,

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the slide valve is not moved and the graduating valve blanks all the ports and stops the flow of air to the brake cylinder.

At the first reduction of an application, the slide valve is moved to service position. It remains in that position throughout the succeeding reductions and is not moved until the brakes are released at the end of the application, when it moves to release position. The exact position of the slide valve therefore depends on the rapidity of the first reduction. If the parts assume quick-service position, Fig. 9, the lap position assumed will be service lap position, Fig. 11. If the

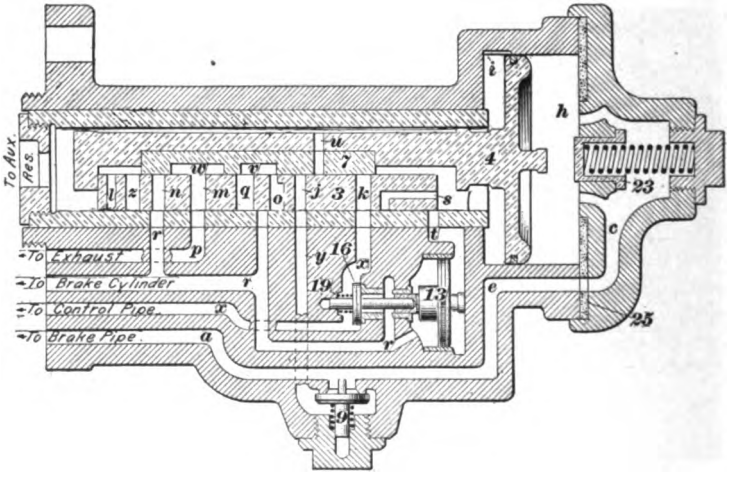

FIG. 12

slide valve moves to full-service position, Fig. 10, the lap position assumed will be with the slide valve in full-service position, but with the graduating valve moved back so as to blank the ports in the slide valve.

10. When the brake valve is moved to release position, the brake-pipe pressure is raised and the triple is moved to charging-and-release position, Fig. 8. In this position, the brake-cylinder air exhausts through ports *r* and *n*, cavity *w*, ports *m* and *p* to the atmosphere. The brakes are thus released. At the same time, the auxiliary reservoir is rechar-

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ging through the feed groove *i* and the two charging ports *x* and *y*, as explained in Art. **6.**

11. If, after the brake valve has been at release position, it is thrown to lap position, the parts of the triple valve will move to **graduated-release lap position,** Fig. 12. If, when releasing the brakes, the brake valve is moved to release position, Fig. 8, and left there, the brake-pipe pressure will be raised and the piston *4* will be held in release position. The brakes will therefore fully release at once and the auxiliary reservoirs will be fully recharged. The brakes can, however, be graduated off if desired. If the brake valve is placed in release position long enough to move the triple piston to release position, and is then moved to lap position, the flow of control-pipe air into auxiliary reservoir through the ports *x* and *k*, Fig. 8, will continue after brake-pipe pressure has ceased to rise. This will raise the auxiliary-reservoir pressure slightly above brake-pipe pressure, which will cause the piston *4* and the graduating valve to move forwards until the graduating valve laps the ports in the slide valve, as shown in the graduated-release lap position, Fig. 12.

In this position, the feed-groove *i* and the charging ports *y* and *x* are all blanked, so that no air can enter the auxiliary to recharge it; also, the exhaust port *n* is blanked, so that the further escape of brake-cylinder air is stopped. As the air in the brake cylinder at the instant that port *n* is blanked is retained in the brake cylinder, the brake is only partly released. By again moving the brake valve to release position and then back to lap, a further reduction of brake-cylinder pressure can be affected; thus, the brake can be graduated off step by step until brake-pipe pressure has been fully restored and the brake-cylinder pressure has been exhausted. This action forms the *graduated-release feature* of the triple valve. The amount of each graduation depends on the amount that the brake-pipe pressure is raised before lapping the brake valve.

12. When the brake valve is placed at emergency position, the resulting sudden and heavy reduction of brake-pipe

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pressure causes auxiliary pressure to force the parts of the triple valve to **emergency position,** Fig. 13. Piston *4* is moved to the right until it strikes against, and makes an air-tight joint with the cylinder-cap gasket *25*.

Air from the auxiliary reservoir passes through the ports *s* and *t* and forces the by-pass piston *13* to unseat the by-pass valve *16*. Control-pipe air then flashes through *x*, *16*, and *r* into the brake cylinder. At the same time, auxiliary air flows through the emergency ports *l* and port *r* into the brake cylinder. Air continues to flow from the control pipe into the

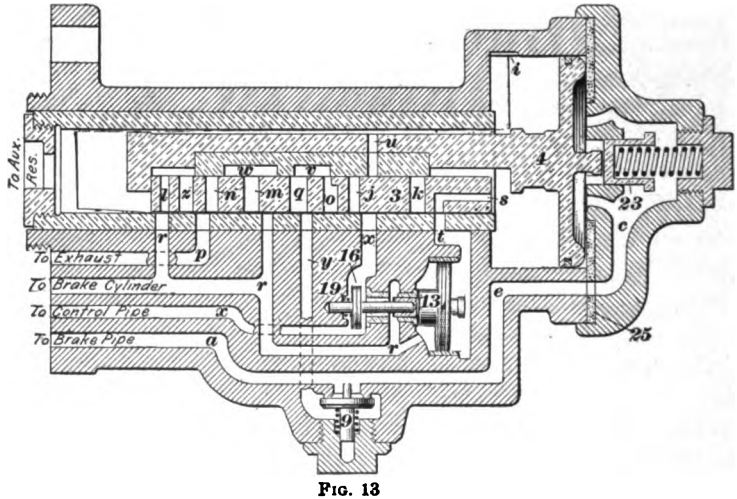

FIG. 13

brake cylinder until the brake cylinder and auxiliary pressures are nearly equal, when the by-pass valve spring *19* forces the valve *16* to its seat and stops the flow of air. Both the graduating valve and the slide valve remain in their emergency positions, so that the brake-cylinder and auxiliary pressures equalize through the ports *l* and *r*.

The emergency port *l* is made smaller than the service port *z* in order to restrict the flow of auxiliary air into the brake cylinder. Thus, by prolonging the time of charging by the smaller port, the control pipe will supply as great a quantity of air as possible to the brake cylinder. On

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account of this restriction, the brake-cylinder pressure in emergency applications rises to within a few pounds of brake-pipe pressure. This constitutes the *high-emergency brake-cylinder-pressure feature* of the M triple valve.

13. Type M-15 Brake Valve.—The brake valve used with the A. M. M. system is known as the **type M-15 brake valve,** and it is shown in Fig. 14. The valve is made in two sizes, the *M–15–D brake valve*, which is used on trains that

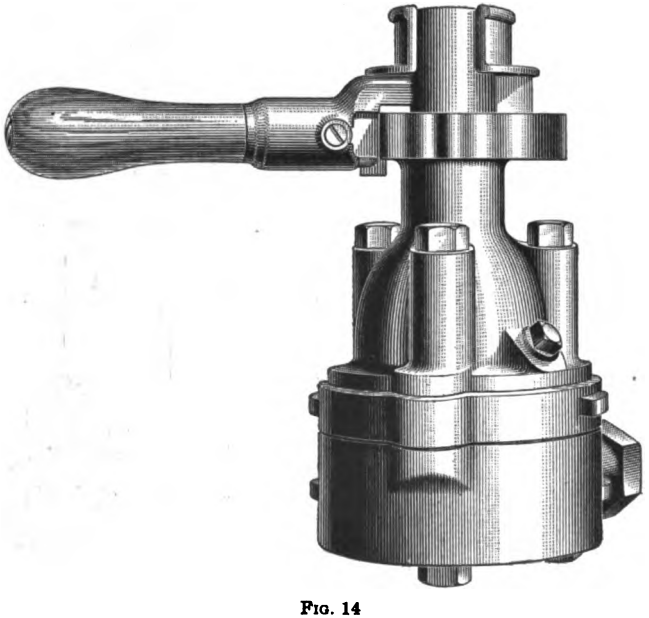

FIG. 14

do not exceed three cars in length, and the *M–15–E brake valve*, which is used on trains from four to eight cars in length.

The brake valve is composed of three parts. The lower part *4*, Fig. 15, is called the *pipe bracket;* the middle section *2*, the *valve seat;* and the top section *3*, the *valve body*. All pipe connections are made to the pipe bracket, so that the brake valve can be removed without disturbing any of the pipe connections by simply removing the three bolts *21*. The two

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fillister-headed screws *18* secure the valve seat to the valve body, thus permitting the brake valve to be removed intact.

The parts of the brake valve are: *5*, rotary valve; *6*, rotary-valve key; *7*, rotary-valve spring; *8*, key washer; *9*, an oil screw that, when removed, permits the rotary key to be oiled through an oil groove; *10*, brake-valve handle; *11*, handle latch that fits into the position notches and locates the position of the brake-valve handle as the handle is moved from

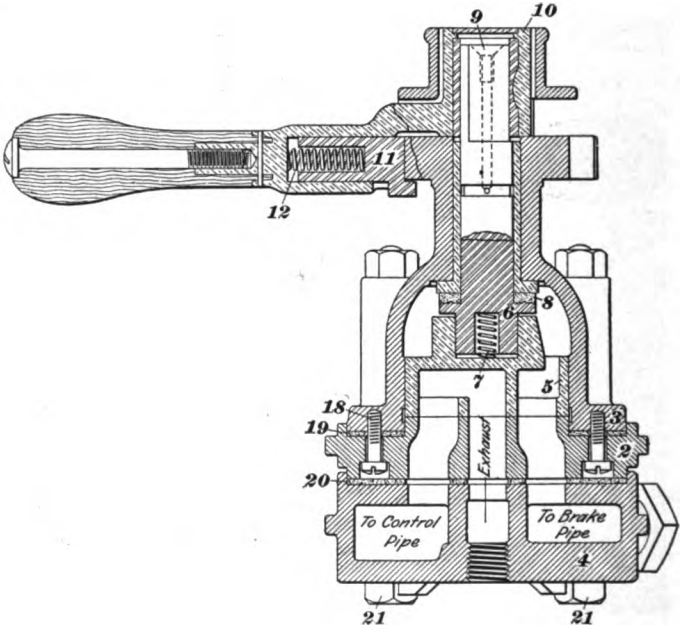

FIG. 15

one position to another; *12*, latch spring that holds the latch forwards against the notches in the valve body; *19*, upper gasket; and *20*, lower gasket. At *22*, Fig. 16, is shown an oil plug that, when removed, permits the rotary valve to be oiled through the passage leading from the plug to the rotary valve.

14. Four pipe connections are made to the pipe bracket, one for the control pipe, one for the brake pipe, one for the

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brake-cylinder exhaust pipe, and one for the brake-valve exhaust pipe. In order to insure that the proper pipe will be connected to the several pipe connections of the pipe bracket, raised letters are cast in the bottom of the pipe bracket. The letter *S* stands for the control pipe; *B P*, for the brake pipe; *B C–E X*, for the brake-cylinder exhaust pipe; and *E X*, for the brake-valve exhaust pipe.

15. The positions of the brake valve are indicated in the plan view of the valve, Fig. 16.

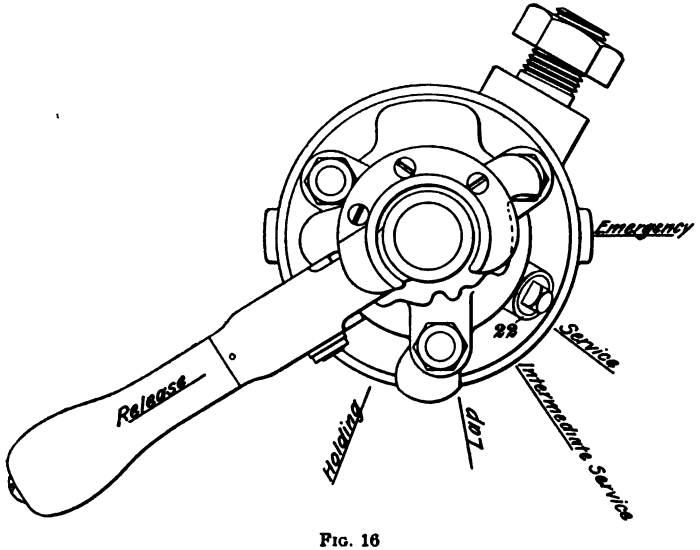

FIG. 16

The brake-valve handle is carried in **release-and-running position** at all times when the brakes are released. The position is also used to release the brakes when they are applied. In this position of the brake valve, the control pipe is connected with the brake pipe. Thus, control-pipe air can pass directly into the brake pipe to charge it and maintain it at the proper pressure. Also, the brake-cylinder exhaust pipe is connected to the brake-valve exhaust pipe, thus permitting any air in the brake cylinder to exhaust to the atmosphere.

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16. In the **holding position,** the control pipe is in communication with the brake pipe, so that air can still flow into the brake pipe. The brake-cylinder exhaust pipe, however, is not connected to the brake exhaust pipe; thus brake-cylinder air is maintained in the cylinder.

17. In the **lap position,** all the ports in the brake valve are blanked except the brake-cylinder exhaust port, which is open to the atmosphere. This is the only position in which the brake-valve handle can be removed from the brake valve; consequently, as the handles are removed from all brake valves except the one being used by the motorman, these brake valves must be in lap position and their brake-cylinder exhaust ports open to the atmosphere.

18. The **intermediate-service position** is used for applying the brakes when the train is a short one. In this position, connection is made from the brake pipe to the atmosphere through a relatively small port opening. This allows brake-pipe air to escape to the atmosphere at the proper rate to make a service application for a short train.

19. The **service position** is used for making service applications of the brakes when the train is full length. In this position, connection is made from the brake pipe to the atmosphere through a larger port opening than is used in the intermediate position. This permits brake-pipe pressure to be reduced fast enough to make a proper reduction for a service application for a train of full length.

20. The **emergency position** is used in actual emergencies, where safety is the important factor and the train must be stopped in the shortest distance possible. This position opens a large port between the brake pipe and the atmosphere, allowing brake-pipe pressure to drop to zero quickly and thus setting the brakes with maximum power.

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OPERATING THE BRAKE

21. Charging the Train.—When inspecting a train preparatory to charging the brake system, see that the first and last cut-out cocks in both the brake pipe and control pipe are closed and that all the other cocks are open; also see that the hose at the end of the train is coupled to the dummy coupling and that all couplings are made properly. Close the cut-out cocks in the brake pipe and in the brake-cylinder exhaust pipe under the rear-end brake valve of the motor car, and open the cocks under the brake valve that the motorman is to use. On the trailers, the cut-out cock in the brake-cylinder exhaust pipe must be open under at least one brake valve of each trailer car that is provided with brake valves, but the cut-out cocks in the brake pipe must be closed under all the brake valves. Lap all the brake valves except the one that is to be operated; also, close all signal-whistle cut-out cocks except the one in the cab of the motor car. All other cut-out cocks must be open on both the motor and the trailer cars. Also, see that all conductor's valves are closed and that all hand-brakes are released. A cut-out cock is open when its handle is crosswise with the pipe; it is closed when the handle is parallel with the pipe. The drain cocks and bleed cocks on all the reservoirs must be closed. In addition, see that the fuses in the compressor circuits on all motor cars are not blown.

22. When the train has been properly inspected, place the brake valve in release and running position and start the compressors by closing both snap switches in the electric circuit of the compressors. As each of these switches open the same circuit, the compressor motor may be stopped by opening either switch. Therefore, both switches must be closed to start the motor.

Air from the main reservoir of each car supplied with a compressor flows through the feed-valve and control pipe to the operating brake valve; it then flows into the brake pipe and through the branch pipe and triple valve into the

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auxiliary reservoir. Air also flows through the control-pipe branch pipe and triple valve into the auxiliary reservoir. As all the air must pass through the feed-valve before entering the control pipe, it follows that the brake system will be charged to the pressure at which the feed-valve is set to operate. When the brake-pipe gauge indicates full brake-pipe pressure, the train is fully charged. The brake should then be tested to determine whether or not it is in good working condition.

23. Testing the Brakes.—When the system is charged, note by the gauge the value at which the feed-valve maintains brake-pipe pressure; also, note the cutting-out pressure of the governor when the compressor stops. During the test, the cutting-in pressure also should be noted. After the brake system has been fully charged, as indicated by the governor stopping the compressor, lap the brake valve to note brake-pipe leakage. The rate at which the black hand of the gauge drops will indicate the extent of the leakage. Next, make a 10-pound to 12-pound brake-pipe reduction from the motor car, to set the brakes, and then lap the brake valve. Pass toward the rear of the train and note the position of the push rod of each cylinder to see whether all brakes have applied and whether or not they are leaking off.

If a brake releases after being applied, it is possible that the cut-out cock under an idle brake valve is not closed, that the brake valve is not lapped, or that the rotary valve is leaking. There may be a leak from the auxiliary reservoir or its connections, the slide valve of the triple valve may be leaking, or the air may be leaking past the brake-cylinder packing leather, allowing the brake to leak off without the triple valve moving to release position. The brake-piston travel may be too short to cover the leakage grooves, allowing the brake to leak off.

If all brakes apply properly and remain on, then move the brake valve to release and running position and let it remain there. Pass along the train and note all brake-cylinder push rods to see whether or not they have moved back to

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full-release position; also, note whether the brake shoes clear the wheels sufficiently to prevent them from dragging.

If a brake that has not released is found, the trouble may be in the triple valve, both cut-out cocks in the brake-cylinder exhaust pipe may be closed, the feed-valve may not have opened, a brake valve may not be properly lapped, a feed-valve on one of the trailer cars may be adjusted higher than the feed-valve on the operator's car, a control-pipe cut-out cock may be closed, or the brake rigging may be caught and thus prevented from moving to release position, although the brake-cylinder pressure may be exhausted. To determine whether the rigging is caught, make a heavy application of the brakes and then release them, noting whether or not the air exhausts from the brake-cylinder of the stuck brake; if it does, but the brake shoes do not leave the wheels, the rigging is "stuck."

24. Next, test to see whether the motor-car brakes will remain on when the brake valve is in the holding position. Make a 15-pound service reduction and place the brake valve in holding position. All the brakes on the trailer cars should release at once, while the motor-car brakes should remain set. If they do not, the brake-cylinder exhaust-pipe cut-out cock on the rear of the train may be open, there may be a leak in the brake-cylinder exhaust pipe, or the brakes may leak off past the brake-cylinder packing leather.

Occasionally, an emergency-application test should be made with both the brake valve and the conductor's valve, to make sure that the emergency application can be obtained if desired.

If one compressor is found to be working much longer than the others when recharging the main reservoirs and when all the other compressors are cut in and are operating, there is probably a heavy leak on the car on which that compressor is installed. The drain cock, or bleed cock, may be open or a pipe may be broken or split. The trouble should be located and remedied before the train is started on its run. If the trouble develops while on a run and cannot be located

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and remedied, the train should be turned in at the first opportunity.

If there is a continuous blow at the main-reservoir safety valve on a car when charging a train, the governor of the compressor on that car is either defective or out of adjustment. In a case of this kind, the compressor switch should be opened so as to cut the affected motor out of service until the governor is put in order. The main-reservoir pressure should be between 85 and 100 pounds.

The control pipe and the brake pipe should have a pressure of 70 pounds when fully charged. If control-pipe pressure is greatly in excess of 70 pounds, the trouble is either in the feed-valve or in the check-valve of the dead pump device.

25. Running Test of Brakes.—It is advisable, if practicable, to make a **running test** of the brakes on all trains when leaving a terminal station and on approaching a drawbridge, to make sure that they hold properly. A running test should also be made when, for any reason, a train has parted during a run, or when it has stood for some time at a station where there is a possibility of some person having closed an angle cock.

The current should be kept on while this test is being made, the motorman simply making a light service reduction to see whether, and how well, the brakes take hold. As soon as he feels the brakes take hold properly, he should release them. While making the reduction, he should note the length of time that the brake pipe exhausts, as by so doing he can judge the length of the brake pipe that is cut into service. In order to obtain the best results in judging the length of a brake pipe, about the same amount of brake-pipe reduction should always be made.

TRAIN CONTROL

26. Reduction and Application.—By the term **reduction** is meant a lowering of brake-pipe pressure; by **application** is meant the applying of the brakes, whether they are

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fully or only partly set. A reduction of brake-pipe pressure will cause an application of the brakes. Every time the brakes are applied and released, the action as a whole is referred to as an application of the brakes.

An application of the brakes may be either a service or an emergency application. When several reductions are made in producing an application, the application is said to be a **service,** or **graduated, application** of the brakes; such applications are referred to as *full service* or *partial service.* In a full-service application, the brake-cylinder and auxiliary pressures equalize, and the brake is set with all the force of the air contained in the auxiliary reservoir; this application may be made with either one or more service reductions. In a partial application, equalization does not take place, and the brake is set with only a part of its full force.

When a sufficiently sudden brake-pipe reduction is made to operate the triples quick-action, the application is said to be an **emergency application,** and the brakes are set with their greatest force in the shortest possible time.

When making a service application of the brakes, the first reduction will depend somewhat on the length of the train and its speed. Whatever the length of the brake pipe, the first reduction must be sufficient to cause the brake-cylinder pistons to move out far enough to cover the leakage grooves; otherwise, the brake will not set, and the air that should have been used in setting it will pass out through the leakage groove and be wasted.

The amount of reduction necessary to cover leakage grooves can be readily determined when testing the train. From 5 to 7 pounds is generally sufficient.

27. Retarding Effect of a Reduction.—The **retarding effect** of a brake-pipe reduction depends on the brake-cylinder piston travel, the speed, and the grade, brake-cylinder leakage being neglected.

28. The auxiliary reservoir and the brake cylinder are so proportioned that when the cylinder piston has a 5-inch

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travel, they will equalize at a pressure of 50 pounds from an auxiliary pressure of 70 pounds. A travel of 5 inches is considered to be the standard piston travel. In other words, the air in the auxiliary under a pressure of 70 pounds will force the piston in the brake cylinder forwards until it has traveled 5 inches, and will expand and fill both the auxiliary and the brake cylinder to a pressure of 50 pounds. The pressure at which the auxiliary and brake cylinders equalize depends on the piston travel of the cylinder piston; the greater the travel the less will be the pressure of equalization.

The brakes with the short travel hold better for a given reduction, give a higher braking power, and attain the full braking power sooner than the brakes having long travel. Inasmuch as the short-travel brake equalizes at a higher pressure than the long-travel brake, it follows that the brake with the long-piston travel is the quickest to release.

29. Experiment has shown that with similar brake-pipe reductions a brake grips the wheel better, and consequently retards the train more, at low than at high speeds. Experiments made in England in 1878 and more recent experiments by the Master Car Builders' Association of the United States have demonstrated that the friction exerted between the wheel and the rail is practically constant at all speeds; that the friction exerted between the brake shoe and the wheel is much less at high than at low speeds, being only one-third as great at a speed of 55 miles per hour as it is when the wheels are only just moving; that on account of this reduction of frictional resistance at high speed, a much greater pressure can be applied to the brake shoe when the speed is high, without danger of sliding the wheels; and that in order to make a brake shoe exert as great a retarding force at high as at low speeds, it must be subjected to a greater pressure at high speeds.

It has been found that under the same conditions, the distance required to stop a train traveling at the rate of 40 miles an hour is about twice as great as when traveling 30 miles. At 50 miles an hour, between three or four times

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the distance is required; and at 60 miles, about five times the distance is necessary.

30. When a train is running on a down grade there is a tendency to acceleration of speed, due to the grade, and this tendency must be overcome by the action of the brake. On the other hand, on an up grade, the force of gravity acts in conjunction with the brake, when applied, to retard the speed of the train. Consequently, for a given speed, a heavier application of the brake must be made to stop or retard a train on a down grade than on a level grade, whereas, on an up grade, a lighter application will serve to produce the same results.

31. Service Stops.—In stopping a train by means of the brake, four things must be observed: (1) The smoothness of the stop; that is, its freedom from the crowding-forward movement, due to retarding the speed too quickly, and the unpleasant jerk as the car stops. (2) The accuracy of the stop; that is, bringing the train to rest at the exact spot intended. (3) The time required to make the stop, the stop being made in such a way as to save the most time possible. (4) The freedom from tendency of the wheels to slide.

Smoothness in a stop requires that the brake application be made according to the speed, that the pressure be low at low speeds, and that the brake be practically released when the train stops, so as to avoid a sudden lurch when the brakes right themselves.

Accuracy requires that the train be under perfect control and that the speed be properly reduced before the stopping point is reached, so that an exact stop can be made.

Saving time requires that the brake application be made quickly and according to the speed. At high speed, a full application should be made promptly and at one reduction, and graduated off as the speed decreases; at low speeds an application low enough for the speed should be made, and then the brake graduated off as before. In other words, the brake should be set with the highest desirable force at once,

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so that the maximum cylinder pressure will be obtained while the speed of the train is highest and the holding power of the brakes is least effective. When the speed has been reduced to about 20 miles per hour, and the brakes are holding better, the cylinder pressure should be reduced by steps, at a rate sufficient to maintain a high rate of retardation without danger of sliding the wheels.

32. To handle a train smoothly during a service stop, make as heavy an application of the brakes as desirable at once and soon enough so that if held on it would stop the train a couple of car lengths short of the proper stopping point. As the speed is reduced and the point approached, graduate the pressure out of the brake cylinder so that only a few pounds of pressure remain when the train stops. If the grade is level, release as soon as the train stops. If on a grade, hold the brakes on until the go-ahead signal is received; then release. As there is but little air in the cylinder under these braking conditions, the train can be started promptly.

In releasing the brakes, move the brake-valve handle to release position and then back to running position. The wave of air set up when the brake is in release position will release the brakes, and the brake valve in running position will prevent overcharging the brake pipe.

33. Emergency Stops.—In cases of emergency, when it is necessary to stop the train in the shortest distance possible in order to save life or to avoid an accident, throw the brake-valve handle to emergency position *and leave it there* until the train has stopped or the danger is past. Even if a partial or a full-service application has been made, the brake-valve handle should be thrown to emergency position. Some of the brakes may have partly leaked off, in which case the emergency application will set them fully.

34. Undesired Quick Action.—Undesired quick action is caused by some triple valve in the train operating quick-action during a service application of the brake. With such a triple in the train, care must be exercised in stopping

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the train not to cause quick action at low speed. If the triple goes to quick action frequently, it will be best to set the brake in emergency position at once, while the speed is high, and then graduate off as necessary. The effect of a quick-action application at high speeds is not uncomfortable, whereas, if the speed is reduced by a service application and quick action then takes place, the passengers in the cars are apt to be severely jarred. The train should be set out at the first opportunity and kept out of service until the triple causing the trouble is replaced.

35. Brakes Applied From the Train.—If, for any reason, the brakes are suddenly applied from the train, the motorman should immediately lap the brake valve and keep it lapped until the train has stopped or the signal to release the brakes is received. The lapping of the brake valve prevents the escape of main-reservoir and control-pipe pressure, thus providing for a quick release of the brakes when the signal to release is received. An application from the train may be due to the opening of a conductor's valve, a burst hose, a rupture in the piping, an emergency trip cock being operated, or the train breaking in two. The emergency trip cock will be explained later.

36. Application of the Brakes by the Conductor's Valve.—The conductor's valve should be used only in an emergency of which the motorman is unaware. When necessary to use the conductor's valve, pull the handle clear down and *leave the valve wide open until the train stops;* then, before leaving it, *close the valve.* If the valve is closed before the train stops, and the motorman fails to place the brake valve in lap position, the brakes will release. If the valve is not closed before the signal to release is given, the brakes cannot be released. The motorman should place the brake valve in lap position the instant he feels the brakes apply, as already explained.

37. Burst Hose.—In case a hose bursts, the important thing is to get the train out of the way so as not to block the

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line. The motorman should lap the brake valve at once. After the train has stopped, replace the brake-pipe hose with an extra one, if carried, or with the hose from the front or the rear of the train, so that all the brakes can be used. If it is impossible to replace the hose, close the cut-out cock on each side of the burst hose and release the brakes back of the burst hose by placing one of the rear brake valves in release position and opening the cut-out cock under it. Carry this brake valve in release position, so as to keep the brakes back of the burst hose released. In cases of this kind, the brakes back of the burst hose cannot be operated by the motorman, but where there is a motor car behind the burst hose, one of the trainmen should be instructed to be prepared to set the brakes from the rear brake valve or by means of a conductor's valve in the event of an emergency or if the motorman whistles for brakes.

The motorman will have complete control of all brakes ahead of the burst hose; but, if less than three-fourths of the train brakes are in use, the hand-brakes on the cars having their brakes cut out should be used to assist in controlling the train when making ordinary stops.

If only non-motor cars are behind the burst hose, the brakes on those cars must be cut out. To do this, close the double cut-out cocks and leave the auxiliary drain cock open on each car to be cut out.

If the burst hose is in the control pipe, replace it if possible. If it cannot be replaced, close the control-pipe cut-out cock just ahead and just behind the burst hose, and *close the main-reservoir cut-out cock on that car and all cars back of it.*

The brakes back of the burst control-pipe hose will be charged from the brake pipe only. They will apply all right, so that the train can be controlled, but the brakes back of the burst hose cannot be graduated off. Care should therefore be observed in releasing the brakes.

38. Burst Brake Pipe.—If the break occurs in the brake pipe proper or in the branch pipe between the double cut-out cock and the brake pipe, close the cut-out cock

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at the ends of the disabled car. Bleed the brake on that car and empty the auxiliary reservoir so as to prevent the brake from creeping on. Place a brake valve of a car back of the disabled car in release position and leave it there to hold the rear brakes off. Then proceed as in the case of a burst hose.

39. Branch-Pipe Rupture.—If the break is between the triple valve and the double cut-out cock, close the cock, open the drain cock in the auxiliary reservoir and keep it open, and proceed with the train.

40. Control-Pipe Rupture.—In the event of a burst in the control pipe or in the control-pipe branch pipe between the double cut-out cock and the control pipe, close the control-pipe cut-out cock just ahead and just back of the burst; also, close the main-reservoir cut-out cock on the disabled car and all cars back of it. This will permit the train to be handled to the end of the run or to the repair sheds. Care must be exercised in releasing the brakes, however, because the brakes behind the burst will not graduate off, but will release fully the first time a release is attempted.

If the control-pipe branch pipe breaks between the triple valve and the double cut-out cock, close the cock to cut out the brake, open the auxiliary-reservoir drain cock and keep it open, and proceed with the train.

41. Application of the Brakes by the Emergency Trip Cock.—The **emergency trip cock** is a special device used in connection with the air-brake system to apply the brakes automatically in case the train passes a danger signal of which the motorman is unaware. Each car is equipped with two trip cocks, located one on each side of the car outside the truck. The trip arrangement is shown in Fig. 17. The trip cock is an ordinary 1-inch cut-out cock *b*, view (*b*), having a fan-shaped handle *c* extending downwards. The cut-out cock is connected to the brake pipe, so that it forms a direct connection to the atmosphere when open and thus sets the brake. The trip *d* is attached to the signal mechanism and is operated by it.

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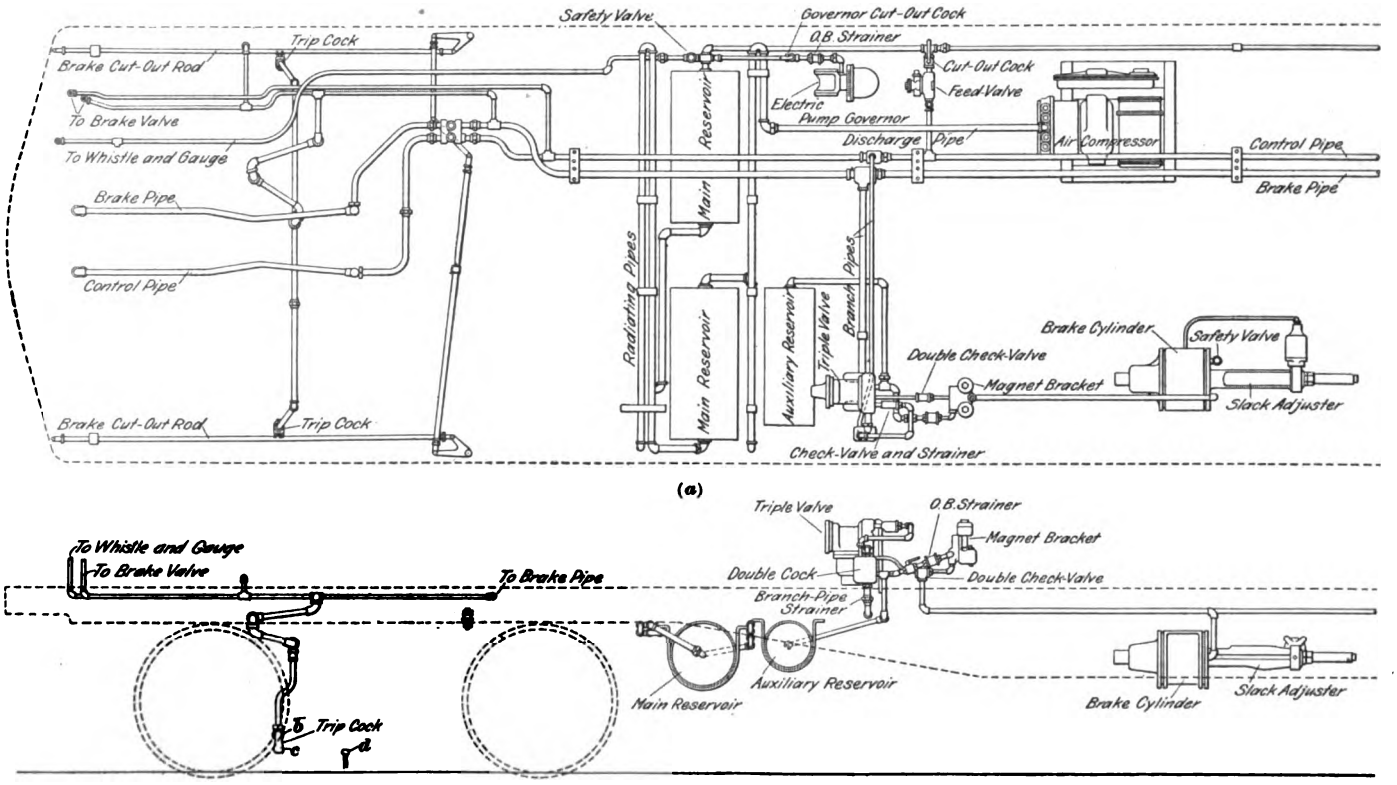

FIG. 17

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The trip is so located that the fan-shaped handle *c* of the cut-out cock strikes it when it is in its raised position. When the signal indicates danger, the mechanism raises the trip *d* so that it stands in a vertical position and high enough to operate the fan-shaped handle *c* of the cut-out cock. When the handle strikes the trip, it is turned to a horizontal position, thus making a brake-pipe opening to the atmosphere and applying the brake and stopping the train. The handle must be moved by hand to its normal position before the brakes can be released.

42. Use of Sand.—It is well known that if sand is used properly the wheels of a train may be made to grip the rails much better and thus lessen the danger of the wheels becoming flat from sliding. On the other hand, if sand is not properly used and the wheels begin to slide, the flat spots formed will be worse than if no sand is used.

When sand must be used in making a stop, the rails under the entire train should be sanded by the time the first application of the brakes is made, or at least before they have applied very hard, and the sand should be used continuously until the train comes to a standstill. Sand should never be used after the wheels have begun to slide; it will not cause them to turn again, but will simply increase the wear on them and thus make the resulting flat spot larger than it otherwise would be. If the wheels are sliding, the brakes should be released sufficiently to permit the wheels to turn; the rails should then be sanded and the brakes reapplied. In such cases, the rails should be continuously sanded until the stop is made. Whenever the rails are bad, sand should be used when applying the brakes, to prevent the wheels from skidding. It is bad practice to try to make a stop without using sand and then, after the brakes have been fully applied and it looks as if the train would not stop soon enough, to drop sand on the rails. Some of the wheels may be sliding at the time, in which event the grinding action between the sand and these wheels will cause some very bad flat spots to form on them.

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43. Wheels Sliding.—When the brakes are applied, there are two forces acting on the wheels: (1) The force exerted by the brake, which tends to prevent the wheel from turning, and thus tends to cause it to slide over the rail like a sled runner; and (2) the force exerted between the wheel and the rail, which resists this tendency to slide, and thus tends to keep the wheel turning. As long as the latter force is greater than the former, the wheel will continue to revolve; but if for any reason the force exerted by the brake is greater, the wheel will slide. It will thus be seen that a wheel may be made to slide either by reducing the adhesion between the wheel and the rail, as when rails are greasy, or by increasing the force exerted by the brake above a certain amount.

Apart from the matter of slippery rails, therefore, the wheels may slide if the piston travel is too short, if the leverage is too great, if the brake fails to release after making a stop, if a heavy reduction is made when the train is moving slowly, or if the auxiliary reservoirs are overcharged and allowed to equalize with the brake cylinders.

44. Cutting Out a Brake.—A brake on a car should not be cut out unless it is absolutely inoperative. By cutting out the brake the total brake power of the train is reduced so much as to be dangerous in the event of an emergency that requires a quick stop. Even if the brake does not hold well in service applications, on account of leaks, etc., it will help very materially in emergency applications and may be sufficient to avert an accident.

To cut out a brake, close the double cut-out cock on the car on which the brake is located, and then release the brake by opening the auxiliary-reservoir drain cock. This drain cock should be left open to prevent leaks from reapplying the brakes.

45. Bleeding Brakes Off.—There are two methods by which a triple valve can be made to release a brake. One method consists in increasing the brake-pipe pressure above that in the auxiliary, and the other consists in reducing the auxiliary-reservoir pressure below that in the brake pipe.

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The first method, in which the brake valve is employed to release the brakes, is the usual one. In the second method, the brakes are bled off. To bleed off the brakes, the drain cock of the auxiliary reservoir should be held open until the air escapes from the triple exhaust port, when it should be immediately closed. The blow of air at the exhaust port indicates that the triple has moved to release position, and any further reduction of auxiliary pressure not only causes a loss of air, but also a reduction of brake-pipe pressure, which in some cases may cause other brakes to apply.

46. Setting Out a Car.—To set out a car of a train, it is necessary first to release the brakes. Next, close the angle cocks on each side of the brake-pipe and control-pipe hose to be parted, and then separate the hose by hand and attach each hose to its dummy coupling. The hose couplings should never be jerked apart by separating the cars while the hose is still coupled up. This operation will not only stretch the hose and make it defective, but will loosen the piping on the car as well. After the car is switched out, the hand-brake should be set so as to prevent the car from moving and causing trouble.

When a train is being laid up, first set the hand-brake of the first car up tight and move the brake-valve handle to release position so as to release the brake; then lap the valve and remove the handle.

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TRAIN SERVICE FOR FIVE OR MORE CARS

TYPE L TRIPLE VALVE

GENERAL CONSIDERATIONS

47. The building of very heavy equipment and the ever-growing demand for more cars in a train and for faster train service at shorter intervals have made it necessary to construct a quick-action triple valve that will control trains consisting of five or more cars smoothly and accurately and with the least waste of time.

The **type L triple valve** was designed to meet these requirements. It is of the pipeless type, because the pipe connections are made to the brake-cylinder head and not to the triple valve. The valve may therefore be removed for inspection or repair without disturbing the pipe joints.

Type L triple valves are used with the same piping arrangement as is used with the type M triple valve. The L triple valve is substituted for the M triple valve, and a supplementary reservoir is added to the equipment for the purpose of furnishing an extra volume of air for emergency applications.

By making a slight service reduction at the brake valve, the triple valve will promptly and effectually apply the brakes, taking air from the brake pipe and passing it into the brake cylinder. In this respect, the operation of the L triple valve is similar to that of the M triple valve. This produces a service application of the brakes without producing an emergency application.

The auxiliary reservoirs recharge promptly after the brakes are released, making it possible to reapply the brakes immediately after releasing, and to obtain a high brake-cylinder

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pressure at each application without carrying a very high brake-pipe and auxiliary-reservoir pressure while the brakes are being released. To assist in the braking operations, a supplementary reservoir about twice as large as the auxiliary reservoir is provided.

The release of the brakes may be retarded without the use of retaining valves, or they may be partly released and again applied with a higher pressure if conditions require it. The air from the supplementary reservoir actuates the triple valve when making a graduated release of the brakes. When an emergency application is required, a very high pressure may be obtained and held in the brake cylinders by simply operating the brake valve in the usual manner. The brake-cylinder pressure during such an application is built up by pressure from the brake pipe, the auxiliary reservoir, and the supplementary reservoir.

DESCRIPTION OF THE L TRIPLE VALVE

48. Outward Appearance.—In regard to its outward appearance, the L triple valve has a different general shape from any of the older forms of triple valve, and, besides, has no pipe connections. Two side views of the L triple valve are shown in Figs. 18 and 19. In Fig. 20 are shown the outlets for the passages in the triple valve body; these ports connect with those in the cylinder head, Fig. 21, and lead to the respective pipe connections. Each triple valve has a letter and number cast on the outside of the valve body, as shown in Fig. 19, to indicate the size of equipment with which it is to be used.

The *L1B valve* is used with 8- or 10-inch brake cylinders; the *L2A valve* with 12- or 14-inch brake cylinders; and the *L3 valve*, with 16- or 18-inch brake cylinders.

With the type L triple valve, the E-7 safety valve should be used, as it takes the place of the high-speed reducing valve used with the high-speed brake. Under certain conditions, which will be explained later, the opening for the safety valve

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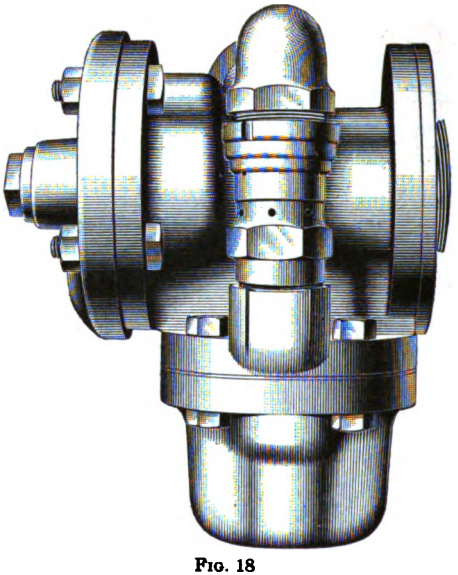

FIG. 18

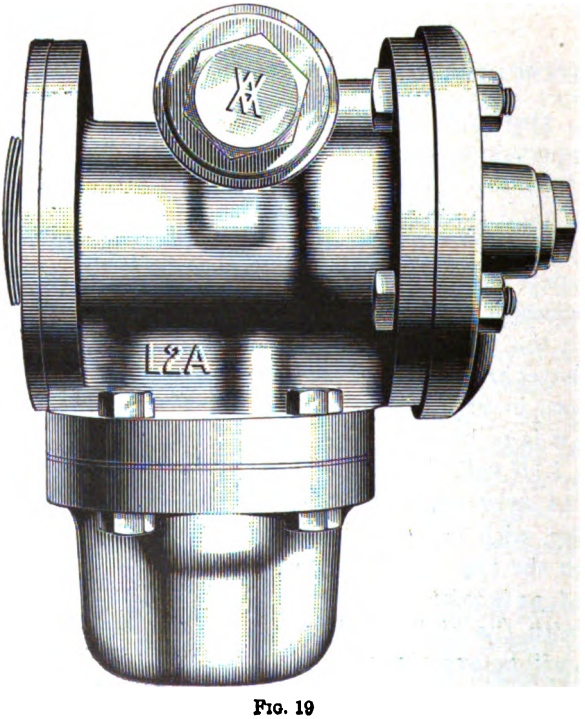

FIG. 19

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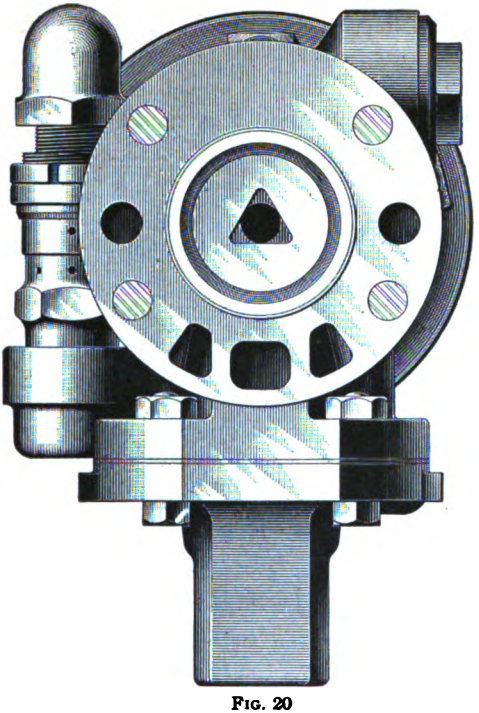

FIG. 20

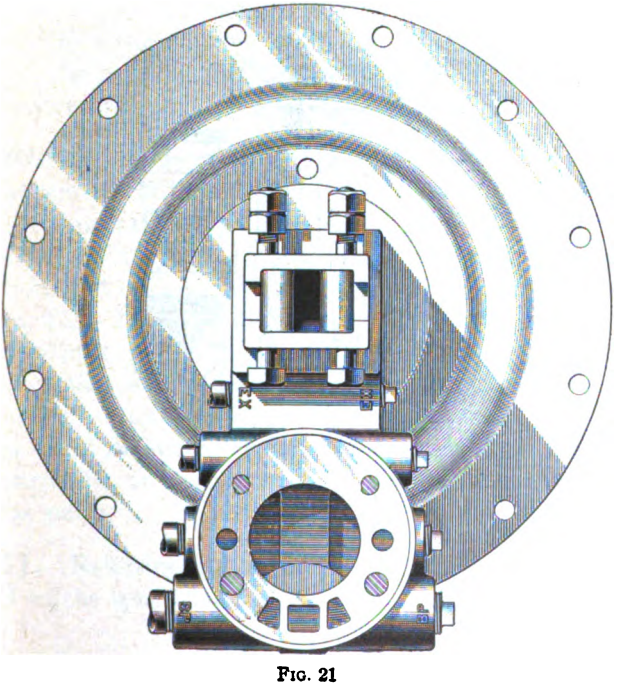

FIG. 21

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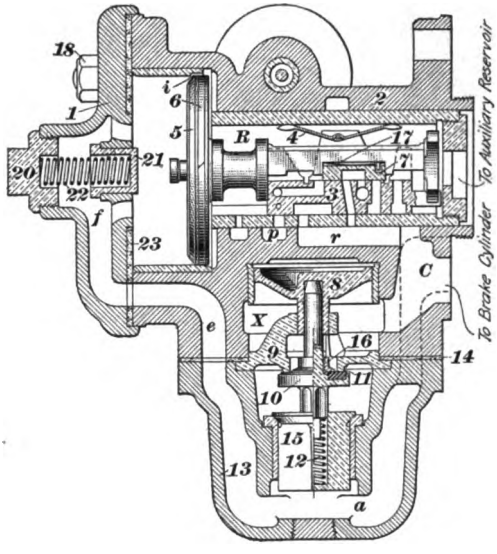

FIG. 22

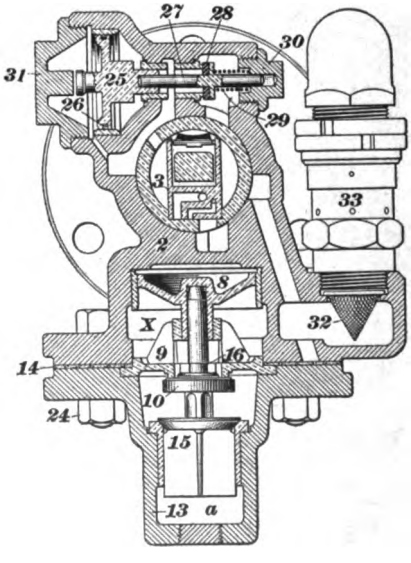

FIG. 23

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may be plugged. Thus, it is apparent that the absence of an E-7 safety valve is not sufficient proof that a certain triple valve is not a type L valve.

49. Inside Parts.—In Figs. 22 and 23 are illustrated two vertical cross-sections of the triple valve. At *1* is shown the cylinder cap; at *2*, the valve body; at *3*, the slide valve; at *4*, the slide-valve spring; at *5*, the triple piston; at *6*, the triple-piston packing ring; at *7*, the graduating valve; at *8*, the emergency-valve piston; at *9*, the emergency-valve seat; at *10*, the emergency valve; at *11*, the rubber seat for the emergency valve; at *12*, the check-valve spring; at *13*, the check-valve case; at *14*, the check-valve case gasket; at *15*, the check-valve; at *16*, the emergency-valve nut; at *17*, the graduating-valve spring; at *18*, the bolt and nut for the cylinder cap; at *20*, the graduating-spring nut; at *21*, the graduating sleeve; at *22*, the graduating spring; at *23*, the cylinder-cap gasket; at *24*, the bolt and nut for the check-valve case; at *25*, the by-pass piston; at *26*, the by-pass piston ring; at *27*, the by-pass valve; at *28*, the by-pass valve seat; at *29*, the by-pass valve spring; at *30*, the by-pass valve cap; at *31*, the by-pass piston cap; at *32*, the strainer; at *33*, the E-7 safety valve.

50. In Figs. 24 to 27, inclusive, is shown the actual arrangement of the ports, cavities, and passages in the graduating valve, slide valve, and slide-valve seat.

All these ports cannot be plainly shown in any single section, and in order to make the connections and operations plain, Figs. 28, 29, 30, 31, 32, and 33, which are conventional illustrations, will be used. In these figures, the mechanical construction and actual proportions have been entirely disregarded. However, reference can occasionally be made to Figs. 24 to 27, inclusive, in order to get an idea of the actual construction of the valves and passages and the proportion of the parts.

51. Referring to Figs. 27 and 28, the port and the passage *c* lead to the space behind the by-pass piston; *b*, to the safety

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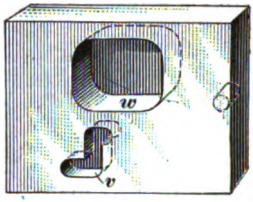

FIG. 24

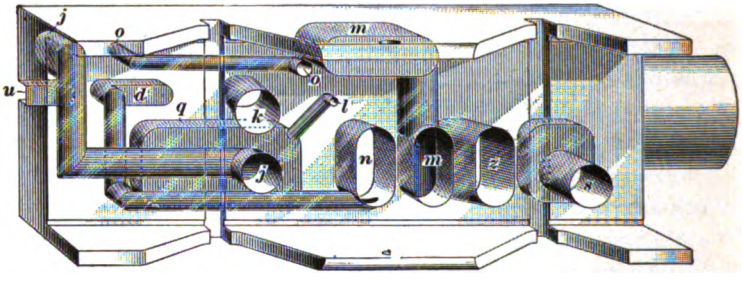

FIG. 25

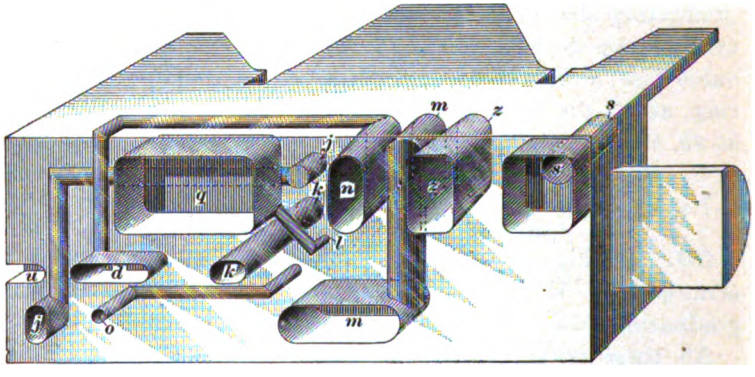

FIG. 26

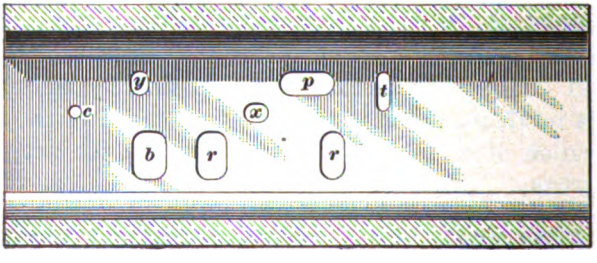

FIG. 27

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valve; *y*, to the check-valve case and thence to chamber *Y*; *r*, to the brake cylinder; *x*, to the space containing the by-pass valve *27* and to the supplementary reservoir; *p*, to the exhaust; and *t*, to the chamber above the emergency piston. In order not to complicate Figs. 22 and 23, the actual connections for the brake pipe and the supplementary reservoir are not shown. These, together with the connection for the brake cylinder and the auxiliary reservoir, are shown in a conventional manner in Figs. 28 to 33, inclusive. The brake-pipe connection is shown at *a*; the supplementary-reservoir connection, at *x*; and the brake-cylinder connection, at *C*. The auxiliary reservoir is connected to chamber *R*, and port *p* leads to the atmosphere.

OPERATION OF THE L TRIPLE VALVE

52. Full-Release and Charging Position.—In the full-release and charging position, air at brake-pipe pressure flows through passages *a* and *e*, Fig. 28, into chamber *H*, moving the triple piston to the right and flowing through the feed grove *i* into chamber *R* and to the auxiliary reservoir. Air in the passage *a* raises the check-valve *15* and passes into chamber *Y*, and since ports *j* in the valve and *y* in the seat register, this air will pass into chamber *R* and the auxiliary reservoir. The port *k* registers with the port *x*, so that the supplementary reservoir will also be charged from the auxiliary chamber *R*; hence, both reservoirs will charge to the same pressure as the brake pipe. Also, air passes from the auxiliary reservoir through port *g* in the valve seat and port *f* to the space behind the by-pass piston *31*, and through port *h* to the chamber in front of this piston. Thus, the pressures on both sides of the piston *31* are balanced and maintained equal, and the valve spring will hold the valve *27* to its seat. The pressures on piston *31* are balanced in all positions of the triple except the emergency position. Brake-cylinder air is free to pass to the atmosphere through the ports *r* and *n*, cavity *w* in the graduating valve, and ports *m* and *p*.

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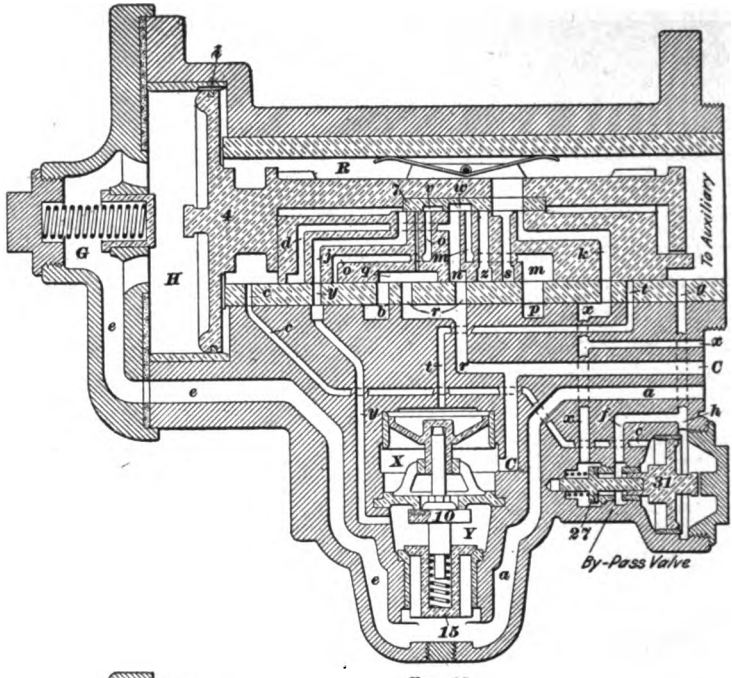

FIG. 28

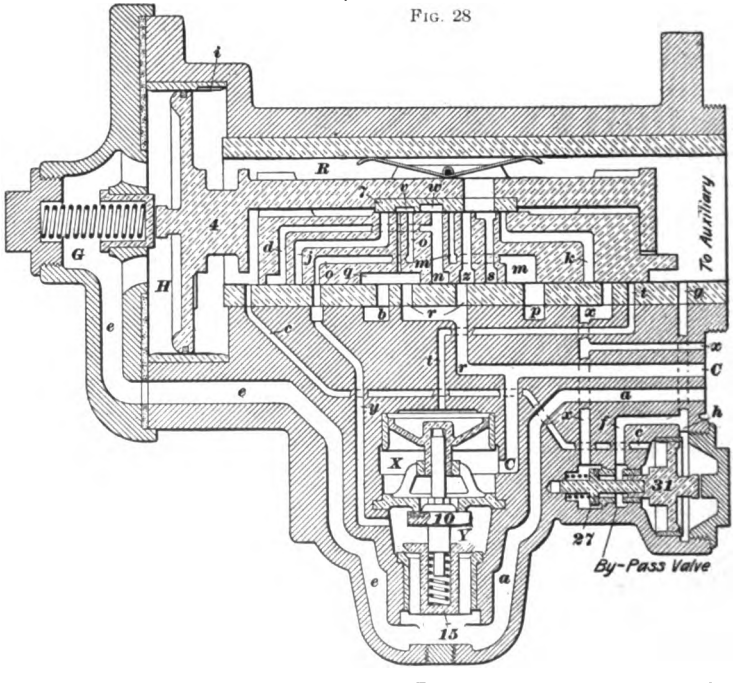

FIG. 29

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53. Quick-Service Application Position.—When a service reduction is made, the pressure in the brake pipe and chamber *H*, Fig. 29, reduces and allows the triple piston to move to the left, closing the feed groove *i* and moving the graduating valve. As the graduating valve moves, it closes ports *j*, *m*, and *k* at the top of the slide valve, thus shutting off communication between the brake pipe and the auxiliary

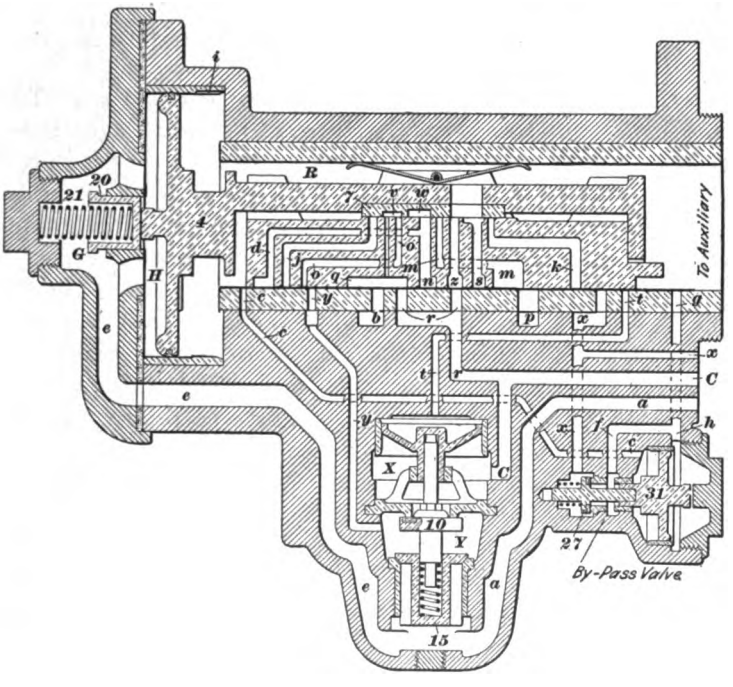

FIG. 30

and between the auxiliary and the supplementary reservoir and closing the brake-cylinder exhaust. It also opens port *z*.

The cavity *v* in the graduating valve connects ports *q* and *o*, and, as the piston continues to move, the end of its stem engages the slide valve and moves this valve against the graduating sleeve to quick-service position, as shown in Fig. 29. Auxiliary air will then pass through port *z* into the brake cylinder and apply the brake; brake-pipe air from

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chamber *Y* will pass through ports *y* and *o*, cavity *v* in the graduating valve, and ports *q* and *r* to the brake cylinder. The pressure in chamber *Y* being partly removed, the check-valve *15* will raise slightly and allow the brake-pipe air to pass, causing a local reduction of brake-pipe pressure at the triple valve and thus assist in applying the brakes. This additional reduction of brake-pipe pressure alone cannot cause an emergency application of the brakes, because the air must pass through the very small opening of port *q*.

54. Full-Service Application Position.—The tendency to produce quick action is also guarded against by proportioning the valves and ports so that the service port *z* will not be wide open while port *y* is connected to the brake cylinder, and any movement tending to compress the graduating spring and increase the opening of the service port *z* will close port *y*, as shown in the full-service position, Fig. 30, and stop the local reduction of brake-pipe pressure. The triple-valve piston stem must slightly compress the graduating spring in order to assume this position. This action always occurs when the train is short, because the pressure in the brake pipe of a short train is reduced more rapidly than that in the brake pipe of a long train. When in either quick- or full-service position, the cavity *q* in the slide valve connects the brake-cylinder port *r* with the port *b*, which leads to the E-7 safety valve. The safety valve is usually set at 62 pounds; consequently, the brake-cylinder pressure cannot raise above this amount during a service application.

55. Service-Lap Position.—After a service reduction has been made by the brake valve, this valve should be moved to lap position, so as to stop the further escape of air from the brake pipe. The auxiliary-reservoir pressure reduces until its pressure is slightly lower than the brake-pipe pressure, when the triple piston and graduating valve will be moved to the right (the graduating spring, if previously compressed, will assist in this movement), until the shoulder on the triple-piston stem strikes the slide valve. The triple

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valve is then in service-lap position, Fig. 31. The slight difference between auxiliary-reservoir and brake-pipe pressure required to move the piston and graduating valve is not enough to overcome the additional friction of the slide valve; consequently, the slide valve will not be moved from either its quick-service or its full-service position. In Fig. 31, the slide valve has been moved to service-lap position from quick-

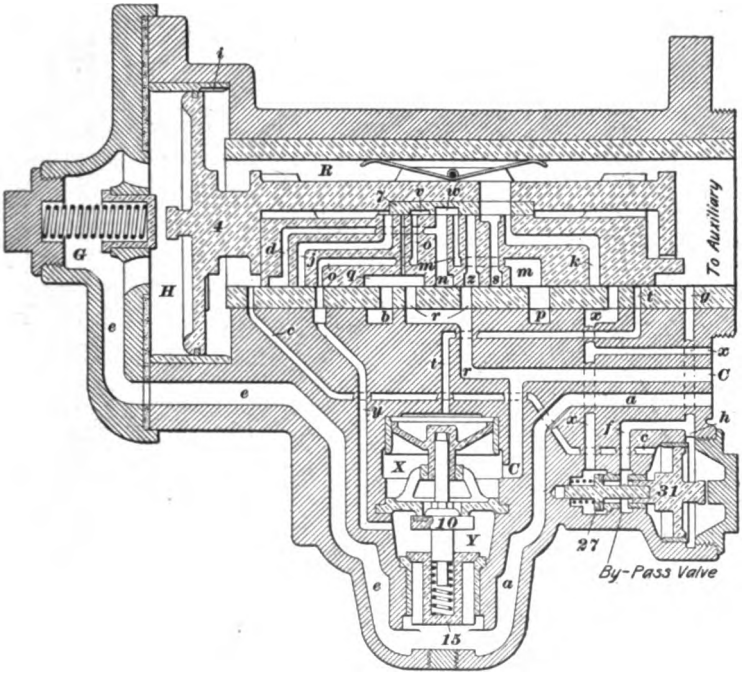

FIG. 31

service position, as indicated in Fig. 29. In these two figures, the similarity of the positions of the slide valve should be noted. In lap position, the graduating valve closes all the ports in the upper face of the slide valve that were open in service position.

56. Release and Recharge.— When releasing the brakes, the brake-pipe pressure in chamber *H* is raised above

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the pressure in the auxiliary reservoir and chamber *R*, thus moving the triple piston, graduating valve, and slide valve to release position, as shown in Fig. 28. In this position, the brake-cylinder pressure will escape to the atmosphere through ports *r* and *n*, cavity *w* in the graduating valve, and ports *m* and *p*, while the auxiliary reservoir will recharge through ports *y* and *j* and through the feed groove *i*. At the same

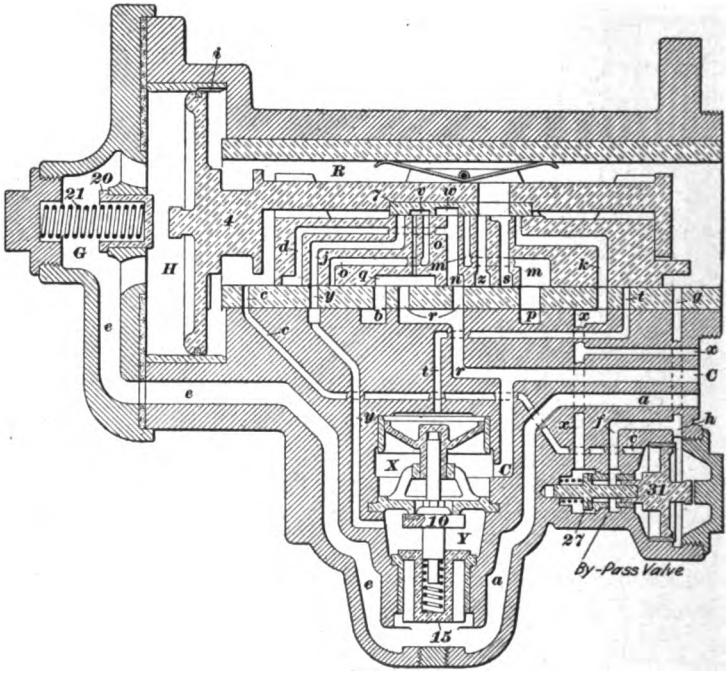

FIG. 32

time, port *x*, which was blanked during the service application, is open to port *k* and the auxiliary reservoir. Since the full auxiliary-reservoir pressure was confined in the supplementary reservoir during the time that the service application was being made, air from that reservoir will now assist in recharging the auxiliary reservoir for a short time. The supplementary reservoir will, however, begin to receive a charge as soon as the pressure in chamber *R* increases.

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During this operation, as well as while graduating the release of the brakes (which will be explained later), the pressures on the brake-pipe and auxiliary-reservoir sides of the triple piston will always be quickly balanced. This insures an immediate response of the brakes to any reduction or increase of brake-pipe pressure, irrespective of what operation may have just preceded. The piston will remain in release position and the auxiliary reservoir and supplementary reservoir will be fully charged, provided the brake valve is left in release position, which is the same as the running position.

57. Graduated-Release Lap Position.—If the brake valve is placed in release position long enough to release the brakes and then placed on lap, the triple-valve piston, the graduating valve, and the slide valve will first be moved to release position; but as soon as the flow of main-reservoir air into the brake pipe ceases, air will continue to flow from the supplementary reservoir through ports *x* and *k*, Fig. 28, into the auxiliary-reservoir chamber *R*, thus raising the pressure enough to move the triple piston and graduating valve to graduated-release lap position, Fig. 32. The graduating valve closes the exhaust port *m*, thus preventing the further flow of air from the brake cylinder to the atmosphere. Port *k* is closed, preventing the passage of air from the supplementary reservoir to the auxiliary-reservoir chamber *R*. Feed-port *i* and port *j* are also closed, and thus cut off the supply of air from the brake pipe to the auxiliary reservoir. In this way, the brake is only partly released, as a portion of the air is held in the brake cylinder.

When releasing the brakes, a series of such graduations may be made until the brake-pipe pressure has been fully restored and the brakes have been fully released. The amount of reduction in the brake-cylinder pressure for any given graduation depends on the amount of air pressure that is put into the brake pipe each time the brake valve is placed in release position during such manipulations. This also will determine the rate at which the brake is recharged.

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58. Emergency Position. — In order to make an emergency application of the brakes, the brake-pipe pressure is suddenly reduced by placing the brake valve in emergency position. As this reduction affects the pressure in chamber *H*, Fig. 33, the greater auxiliary-reservoir pressure will force the triple-valve piston to the extreme left, compressing the graduating spring and moving the slide valve and graduating

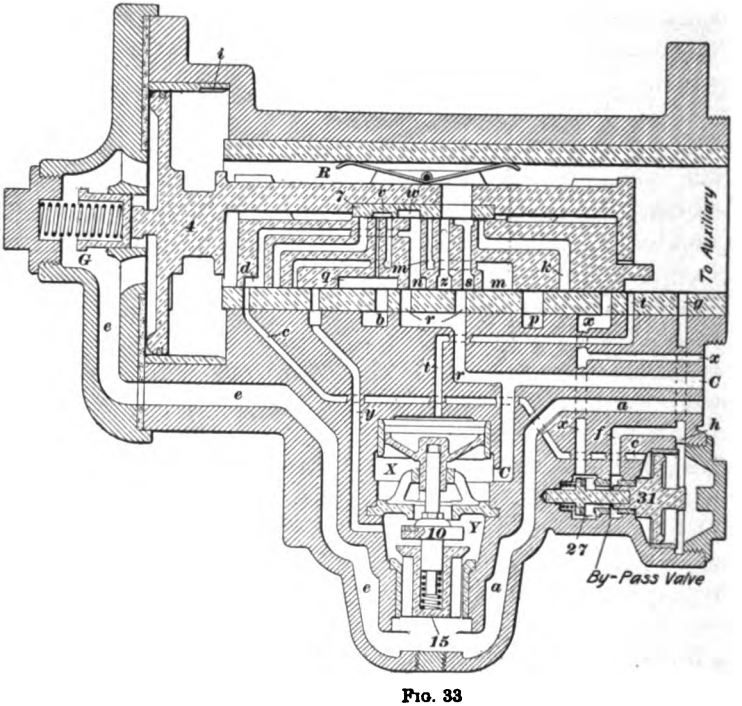

FIG. 33

valve to the emergency position, as shown in Fig. 33. In this position, the auxiliary-reservoir pressure enters the brake cylinder through port *s* in the slide valve and port *r* in the seat instead of through port *z*, as during a full-service application. The slide valve uncovers port *t*, allowing auxiliary-reservoir pressure to enter the chamber above the emergency piston *8*, Figs. 22 and 33, thus forcing the emergency piston down,

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thereby unseating the emergency valve *10*, Fig. 33, and allowing the air from chamber *Y* to escape into the brake cylinder through port *C*. Brake-pipe air will then raise the check-valve *15* and pass into the brake cylinder through chambers *Y* and *X* and port *C*, as is the case in the ordinary quick-action triple valve.

Port *d* in the slide valve registers with port *c* in the seat and allows air in the chamber back of the by-pass piston *31* to escape to the brake cylinder through the ports *c*, *d*, *n*, *r*, and *C*, Fig. 33. As there is no pressure in the brake cylinder at this instant, the by-pass piston will be moved to the left by auxiliary-reservoir pressure and will unseat the by-pass valve *27*, thus connecting the supplementary reservoir with the auxiliary reservoir through *x*, valve *27*, *f*, *g*, and auxiliary-reservoir chamber *R*. This gives, in effect, an auxiliary-reservoir volume approximately three times as great as the one that supplies air to the brake cylinder during a service application. The by-pass valve will remain unseated until the auxiliary-reservoir and brake-cylinder pressures are nearly equal to the pressure remaining in the supplementary reservoir, when the by-pass valve spring will close the by-pass valve *27* and cut off the connection.

The emergency action results in a brake-cylinder pressure nearly equal to maximum brake-pipe pressure, and as the safety valve is not connected to the brake cylinder, port *b* being blanked, this high pressure will not be reduced, but will be held in the brake cylinder until the brake is released in the usual manner.

59. Precautions. — When a car equipped with an L triple valve is to be used in conjunction with the standard type P triple valve, the cut-out cock in the pipe leading to the supplementary reservoir should be closed.

Cars equipped with L triple valves and intended to be used for a considerable length of time with other standard triple valves are usually not supplied with safety valves and supplementary reservoirs. In such cases, the passages leading to these parts must be plugged. When such cars are used in

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high-speed service with other cars having high-speed brakes, an ordinary high-speed reducing valve is required; also, a retainer should be provided in any case where the conditions of service require it.

ELECTROPNEUMATIC AUTOMATIC AIR BRAKE

GENERAL CONSIDERATIONS

60. The **electropneumatic automatic air brake** consists of an electric air brake and an automatic air brake. These brakes are combined in such a way as to use the same brake valve and the same brake cylinder. The electric part of the brake is practically an electric straight air brake, and it is used in combination with the A. M. M. automatic air brake to form the **A. M. M. E. brake system.**

One of the important advantages of the electric control of the brakes lies in the fact that the electric current will operate all the magnet valves at exactly the same instant, regardless of the length of the train; consequently, all operations of the brake take place on all cars simultaneously.

The pneumatic brake requires an appreciable period of time for the effect of any change of pressure to traverse the entire length of the brake pipe so as to operate all the triple valves. The action of the devices in the electric control system is much quicker. With electric control, the length of time the brake valve is held in application position to make a given application does not vary, no matter how many cars are in the train, because the application does not require a brake-pipe reduction. With the pneumatic brake, the length of time the brake valve must be held in application position for a given reduction varies with the length of the brake pipe. The time element, therefore, is eliminated with the electric control, and the motorman is better able to judge the amount of the reduction made.

The brake can be graduated on or applied full force with one reduction, can be held on as long as desired, and can be either graduated off or fully released at once.

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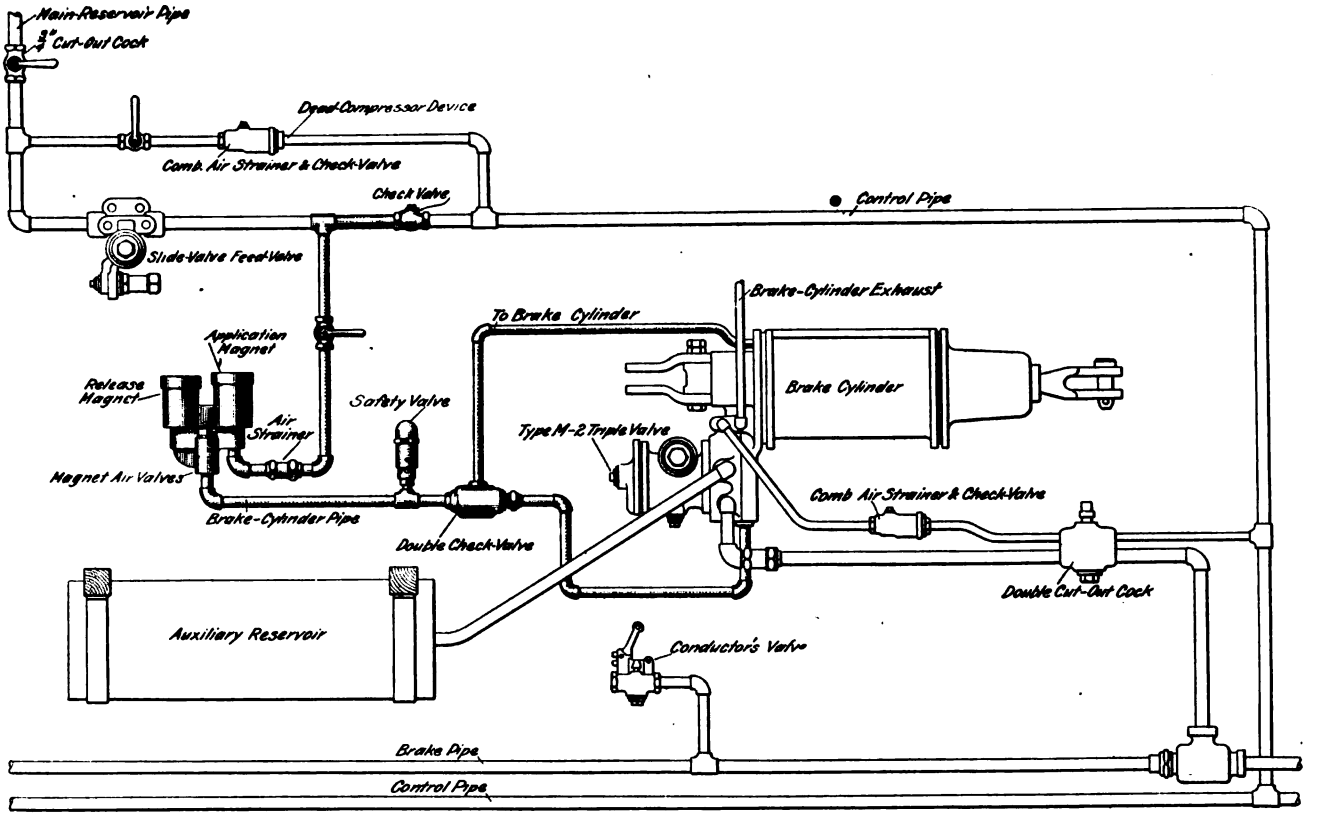

FIG. 34

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PIPE ARRANGEMENT OF THE A. M. M. E. EQUIPMENT

61. The pipe arrangement of the A. M. M. E. system is shown in Fig. 34. By comparing this arrangement with that shown in Fig. 1, it will be seen that the piping is exactly the same as that of the A. M. M. system, except for the additional piping that is required properly to connect up the apparatus used with the electric air brake. The piping and the additional apparatus needed to change the A. M. M. system into an A. M. M. E. system are indicated in the piping diagram by the shaded portions of the figure.

As the apparatus required for the pneumatic part of the brake system has been described in connection with the A. M. M. system, it will not be taken up in connection with this brake system.

62. The parts that pertain to the electric brake are the *magnet air valves*, which consist of two magnet valves mounted on a common bracket; the *application magnet valve* controls the admission of air to the brake cylinder; and the *release magnet valve* controls the release of brake-cylinder air from the cylinder.

The *double check-valve* is used to cut off the triple-valve connection to the brake cylinder when the brakes are controlled electrically; also, to cut off the magnet-valve connection when the brakes are controlled pneumatically. The safety valve is used to prevent excessive pressure in the brake cylinder when the brake is being operated electrically. The check-valve is located in the control pipe, between the magnet-valve pipe and the dead-compressor connection. It permits air to flow from the feed-valve to the control pipe, but prevents a back flow of air from the control pipe toward the feed-valve and the magnet valves. The M-15 type of brake valve used with the A. M. M. system is replaced with the ME-15 brake valve, which has an electric top that permits this single brake valve to operate the brakes either electrically or pneumatically. The *dead-compressor device* is not necessarily a part of either the electric or the pneumatic brakes. It is

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merely a by-pass around the feed-valve that permits control-pipe air to recharge the main reservoir on a car slowly if the compressor fails to maintain the pressure in the reservoirs above 70 pounds. The *combined air strainer and check-valve* prevents main-reservoir air from passing into the control pipe by way of the by-pass instead of through the feed-valve. If this check-valve should happen to leak, the by-pass should be cut out by closing the cut-out cock; otherwise, this cock should be open.

CONSTRUCTION AND OPERATION OF THE MAGNET VALVES

63. The **magnet valves** are located on a special bracket inside the car. They are operated electrically, and can be made to admit air to the brake cylinder to apply the brake, either graduating the brake on or applying it in full the first time; to retain the air to hold the brake on; or to exhaust the air from the brake cylinder either to graduate the brake off or to release it promptly.

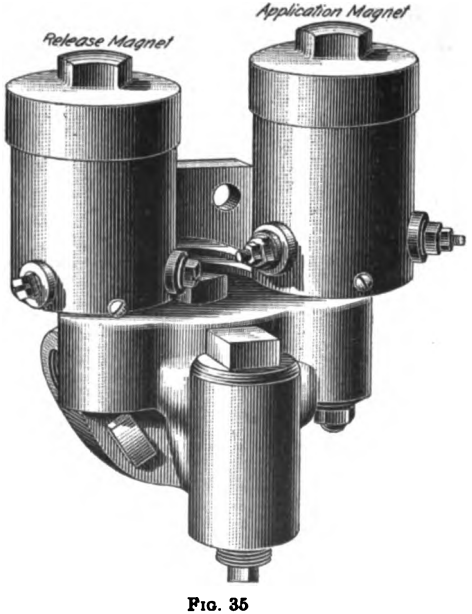

FIG. 35

Fig. 35 shows a perspective view of the two magnet valves and their supporting bracket; Fig. 36, a plan view of the valves and bracket; Fig. 37, a vertical section on the line *U V*, Fig. 36; Fig. 38, a vertical section on the line *Y Z*, Fig. 37; and Fig. 39, a vertical section through the valve body on the line *W X*, Fig. 36.

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In these illustrations, the application magnet is shown at *A*; the release magnet, at *R*; the valve body, at *3*; and the pipe

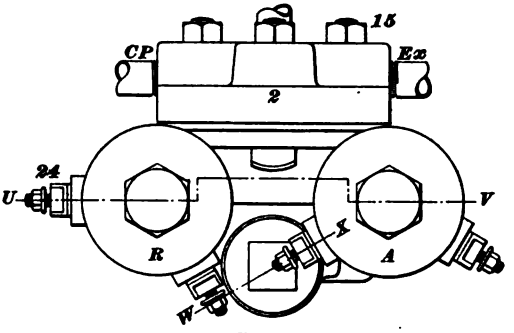

FIG. 36

bracket, to which all pipe connections are made so that the valve can be removed without disturbing the pipe connections, at *2*. The valve body is secured to the pipe bracket

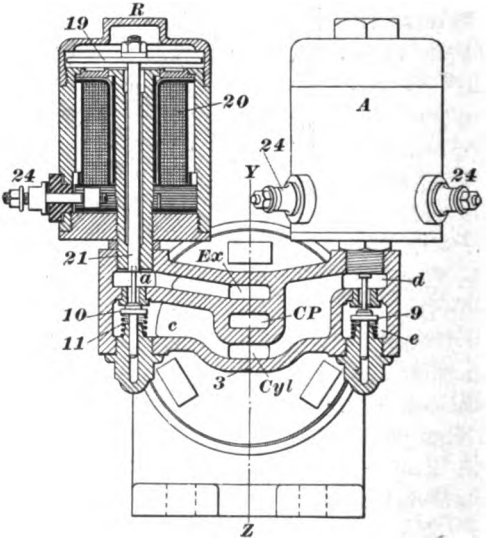

FIG. 37

by means of bolts *15*, and the electric wires are connected to binding posts *24*.

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64. The two magnets are constructed alike and are interchangeable. As shown in Fig. 37, they consist of an energizing coil *20* and an armature *19* having a plunger *21* secured to it. The lower end of the plunger rests on the release valve *10*, and the valve is held up against its seat by the release spring *11*. The energizing coil *20* of the release magnet pulls the armature *19* downwards and unseats the release valve *10*, thus connecting the brake cylinder with the exhaust. The magnet *A* operates in the same way to open the application valve *9*. When the current is turned off from a magnet, the spring *11* raises the plunger and seats the valve.

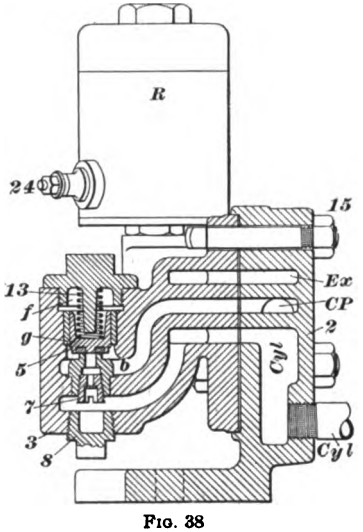

FIG. 38

The passage *Ex*, Figs. 37 and 38, leads from the chamber *a*, Fig. 37, above the release valve *10* to the exhaust pipe *Ex*, Fig. 36. The passage *CP*, Fig. 37, leads from the control-pipe connection to the chamber *b*, Fig. 38, surrounding the supply valve *5*. The passage marked *Cyl*, Fig. 37, leads from the pipe connection of the brake cylinder, Fig. 38, to the chamber *c*, Fig. 37, below the release valve *10* and to the chamber *d* above the application valve *9*. The chamber *e*

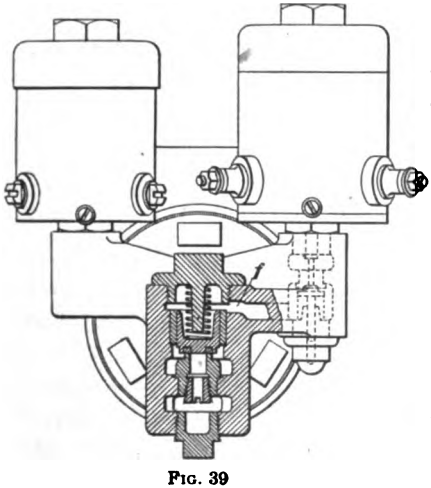

FIG. 39

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below the application valve *9* leads to the chamber *f*, Fig. 38, above the supply valve *5*.

The supply valve has a small port *g*, Fig. 38, drilled through it in such a position that it connects chambers *b* and *f* and allows the air pressure to equalize. Thus, when in release position, the supply valve *5* is held to its seat against control-pipe pressure in chamber *b* by the combined force of the supply-valve spring *13* and the control-pipe pressure above the valve that has been established by air passing through *g*.

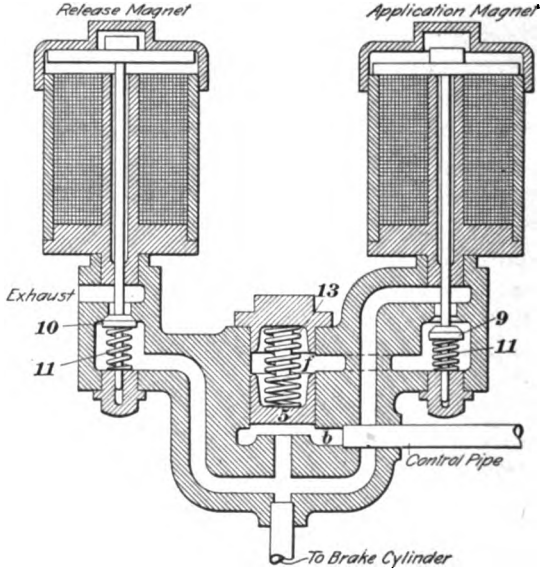

FIG. 40

The supply valve is opened by reducing the air pressure above it so that the pressure in chamber *b* can force the valve from its seat; it is closed by restoring the pressure above the valve.

The choke plug *7*, Fig. 38, controls the rate at which air flows from the control pipe into the brake cylinder. The size of the opening through the plug depends on the size of the brake cylinder, a plug of suitable size being used for each size of brake cylinder.

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65. The operation of the magnet valves can best be explained by means of the conventional illustrations shown in Figs. 40, 41, and 42. There are only three positions of the magnet valves, namely, application position, exhaust or release position, and lap position.

66. Application and Lap Positions.—The position that the parts of the valve assume in making an application of the brake is shown in Fig. 40. The application coil, being energized, unseats the valve *9* and vents chamber *f* air into

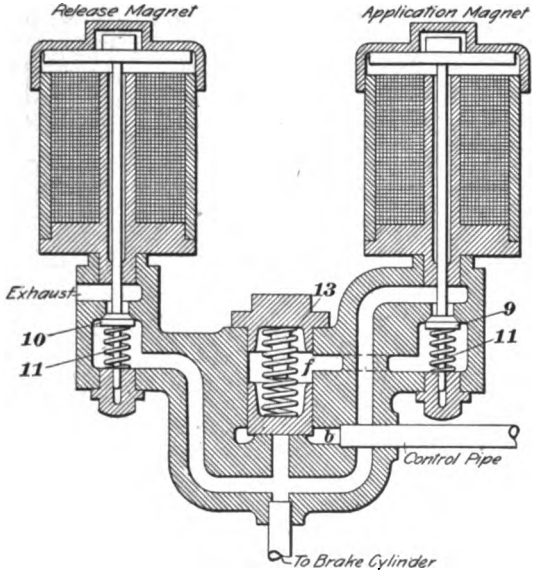

FIG. 41

the brake cylinder. This removes the air pressure from above the supply valve *5*, and air at control-pipe pressure then raises the valve and allows control-pipe air to discharge into the brake cylinder through the choke plug *7*, Fig. 38. When the brake valve is moved to lap position, Fig. 41, the current is cut off from the magnet and the spring *11* seats the application valve. This prevents the further escape of chamber *f* air, and the air pressure of chamber *f* quickly equalizes with

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that of chamber *b* and the supply valve is seated by the spring *13*. In this position, the release valve *10* is closed; thus the air in the brake cylinder is retained and the brake is held on. Each time the brake valve is moved to application position and then to lap position, the preceding cycle of events takes place. Therefore, the brake either can be applied in full at once or can be graduated on. The amount of air admitted to the brake cylinder depends on the length of time the brake valve is kept in application position; thus, either a partial or a full application of the brake can be obtained at will.

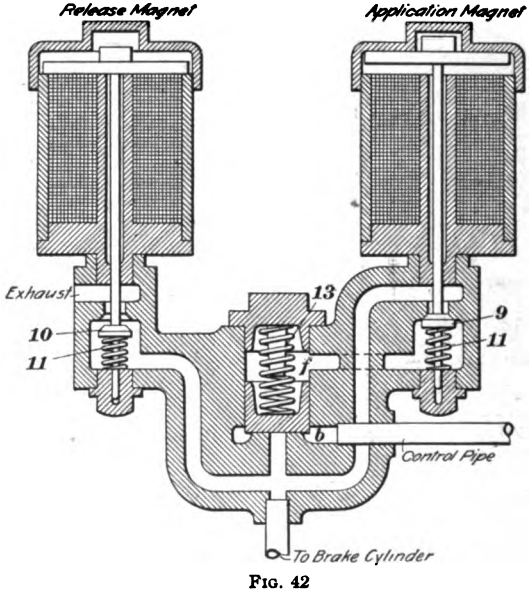

FIG. 42

In making a full-service application, chamber *f* pressure is maintained equal to brake-cylinder pressure, which is constantly increasing; consequently, when the brake-cylinder pressure together with the force of the spring *13* is sufficient to overcome the pressure in chamber *b*, the supply valve will be seated automatically, even though the brake valve is still in application position. The strength of spring *13* determines the pressure at which this will occur. For exam-

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ple, if the spring is set for a pressure of about 10 pounds per square inch and the control-pipe pressure is 70 pounds, the supply valve will be automatically closed as soon as brake-cylinder pressure raises to 60 pounds, whether the application valve *9* is open or not. However, after the supply valve *5* closes, air still passes from chamber *b*, Fig. 38, through the small equalizing port *g*, and if the application valve *9*, Fig. 40, is unseated, it will pass through valve *9* to the brake cylinder and continue to raise the brake-cylinder pressure. To prevent the brake-cylinder pressure from rising too high, the safety valve is used in the brake-cylinder pipe, Fig. 34.

67. Exhaust Position.—To exhaust the air from the brake cylinder, the brake valve is moved to release position, Fig. 42; this energizes the release magnet and unseats the release valve *10*, thus opening communication between the brake cylinder and the exhaust port. When the brake valve is moved to the lap position, the release magnet, Fig. 42, is demagnetized and thus causes the release valve to be closed. The brake, therefore, can be entirely released by leaving the brake in release position sufficiently long, or it can be graduated off by moving the brake valve to release and back to lap and repeating the movement, as desired.

TYPE ME-15 BRAKE VALVE

68. The **type ME-15 brake valve** consists of two parts, namely, the pneumatic and the electric. The pneumatic part is the same as in the M-15 brake valve. Above the pneumatic part is constructed a suitable enclosed chamber in which is mounted insulated contact points to which the wire connections are made (see Figs. 43 to 49, inclusive). This constitutes the electrical part of the brake valve. Contact No. *1*, Fig. 47, has attached to it a wire from the storage battery, and contact No. *2* has attached to it a wire that runs throughout the train and that is connected to the release magnet coil on each of the cars. Contact No. *3* is connected to a wire that runs throughout the train and that connects with the

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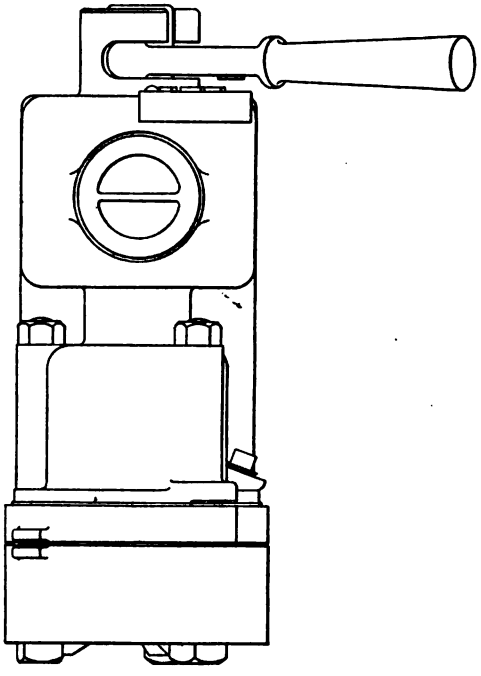

FIG. 43

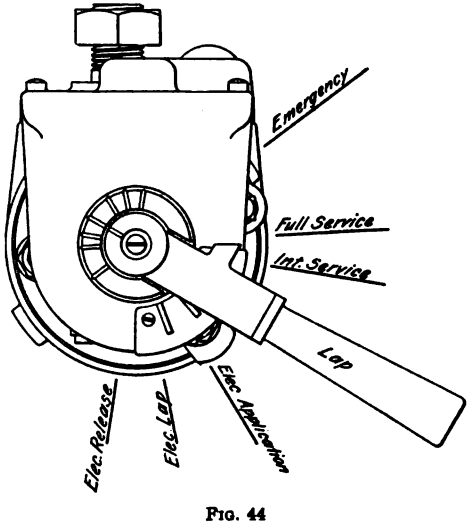

FIG. 44

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application magnet on each of the cars. The valve stem is made longer than in the M-15 valve and is fitted with a contact drum *36*, Fig. 45, by means of which the brake-valve handle may be made to connect contact No. *1* with contacts Nos. *2* or *3*, Fig. 47, thereby energizing their respective magnet coils throughout the train.

There are seven positions of the brake-valve handle, as indicated in Fig. 44.

69. Release and Running Position. The release position, Fig. 47, is for both the pneumatic and the electric part of the brake. For the electric control, it energizes the release-magnet coil, which causes the release valve to be held open and thus connect the brake cylinder with the atmosphere, reducing the brake-cylinder pressure and releasing the brake. For the pneumatic control, it also connects the brake cylinder with the exhaust and releases the brake. At the same time, air passes from the control pipe to the brake pipe, thereby charging the brake pipe to feed-valve pressure and recharging the auxiliary reservoirs. The sector of the pneumatic control is made so long that while the brake handle is moved through the three electrical positions, the pneumatic part of the brake is still maintained in release and running position; consequently, the triple valves are held in release position during the electric control of the brakes.

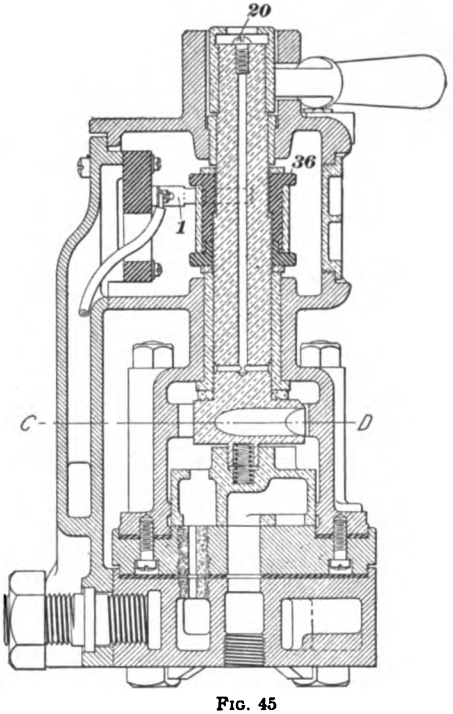

FIG. 45

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70. Electric Lap Position.—The electric lap position, Fig. 48, is used to hold the brakes applied when under

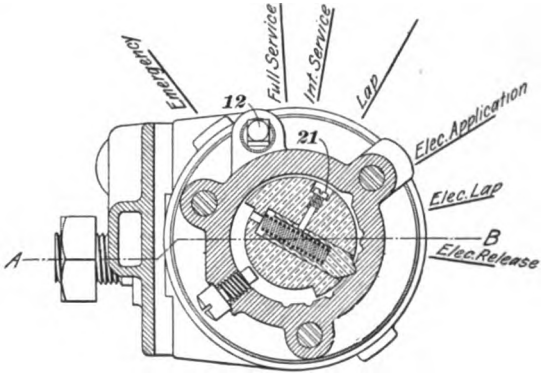

FIG. 46

electric control. In this position, neither of the magnet coils is energized; consequently, the plungers of both magnets are in their upper positions and their corresponding valves are held closed. Therefore, any pressure that is in the brake cylinder will be retained there and the brake will be held on.

71. Electric Application Position. — The electric application position, Fig. 49, is used to make an applica-

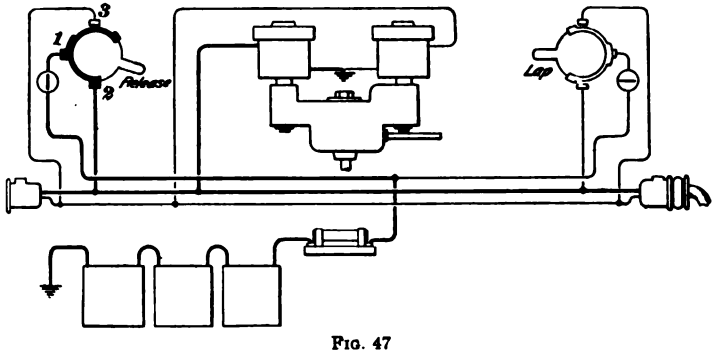

FIG. 47

tion of the brakes under electric control. In this position, the application magnet is energized and thus opens the appli-

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cation valve and permits air to pass from the control pipe to the brake cylinder, applying the brake.

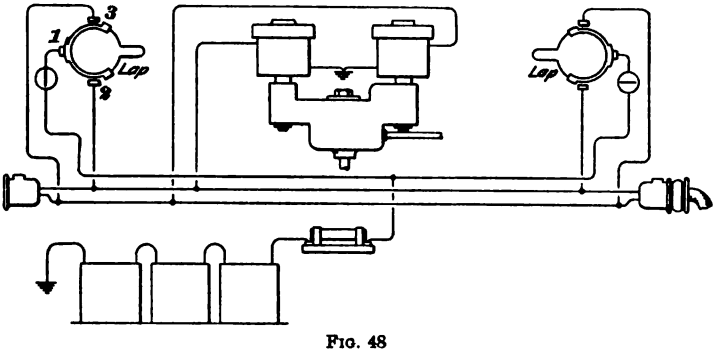

FIG. 48

72. Wiring Diagrams for Electric Control.— In Fig. 47 is shown the electric connections when the brake valve is in electric release position. The lap position is shown in Fig. 48, and the application position in Fig. 49. The inactive brake valves are left at lap position. Under ordinary conditions, the train is controlled by means of the electric control, so that the brake valve is manipulated between electric release and electric application positions only. If the electric control should fail to operate the brake, or in cases

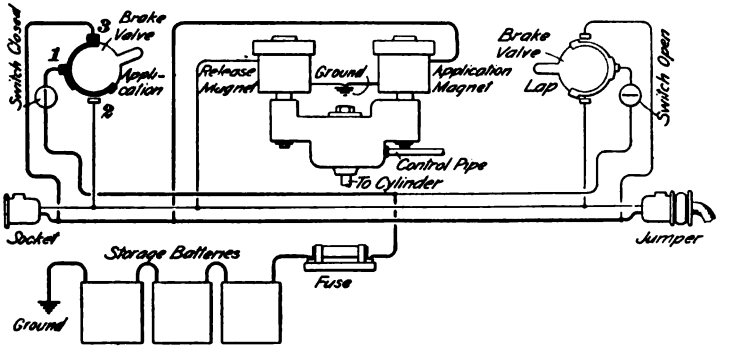

FIG. 49

of extreme emergency, where an emergency application is necessary, the valve handle is moved to the emergency posi-

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tion of the pneumatic control positions and the brake is operated pneumatically. Ordinarily, however, the electric control is used and the pneumatic brake is completely charged and ready for instant use in case of necessity.

DOUBLE CHECK-VALVE

73. Construction.—The **double check-valve** is placed in the pipe leading from the magnet valves to the brake cylinder; it connects the brake cylinder with the triple valve and the magnet valve through their respective pipes. The double check-valve is shown in Fig. 50. The piston is shown at *7*; the piston rod, at *4*; and the slide valve, at *5*. The

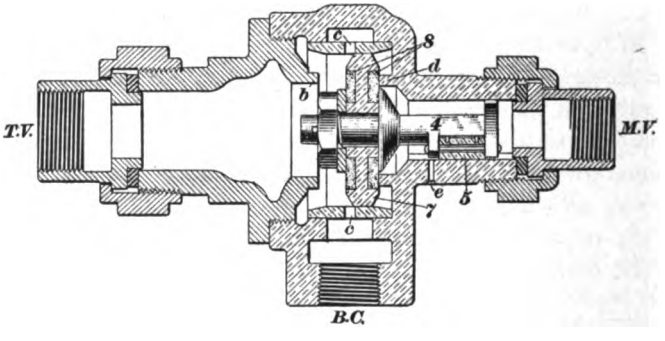

FIG. 50

leather valve faces *8* make an air-tight joint when forced against the valve seat.

The piston *7* is of such thickness that when it rests against its seat *d*, the ports *c* through the valve bushing connect the brake-cylinder connection *B.C.* with the triple-valve connection *T.V.* When the piston rests against the seat *b*, the ports *c* connect the brake-cylinder connection *B.C.* with the magnet-valve connection *M.V.* Port *e* in the magnet-valve end of the check-valve is controlled by the slide valve *5*. When the piston is over against the seat *b*, valve *5* covers port *e*, and when it is over against the seat *d*, valve *5* uncovers port *e*, which then connects the magnet-valve pipe to the

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atmosphere and prevents any accumulation of air in that pipe on account of leakage past the magnet valve.

74. Operation. — When the pneumatic control is used and the brake is being applied, the air from the triple valve enters the double check-valve at connection *T.V.* and forces the piston 7 against the seat *d*, thus preventing the escape of air through the magnet-valve connection; at the same time, it permits the air from the triple valve to pass through the ports *c* to the brake cylinder *B.C.* and to apply the brake. Brake-cylinder pressure holds the piston 7 against seat *d* until the brake is released.

Under electric control and when the brake is being applied, the air from the magnet valve enters the double check-valve at the connection *M.V.* and forces piston 7 to the left against the seat *b*. This prevents the escape of air through the exhaust port *e*, and at the same time permits air from the magnet valve to pass through ports *c* to the brake cylinder and to apply the brake.

DEAD-COMPRESSOR DEVICE

75. The **dead-compressor device** is not really a part of either brake system. It consists of a by-pass that encircles the slide-valve feed-valve, and has a combined air strainer and check-valve so placed in it that air from the control pipe can pass through the check-valve into the main-reservoir pipe. The check-valve, however, will prevent main-reservoir pressure from passing into the control pipe by way of the by-pass. The cut-out cock in the by-pass is to be used only in case the check-valve leaks.

If a compressor fails to maintain the pressure in its reservoir above 70 pounds, the by-pass will permit the main reservoir on that car to be slowly recharged from the control-pipe supply.

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COMBINED STRAINER AND CHECK-VALVE

76. A type of **combined air strainer and check-valve** is illustrated in Fig. 51, in which the valve body is shown at *2*; the cap nut, at *3*; the check-valve, at *4*; the check-valve spring, at *5*; the valve cap, at *6*; the two perforated strainers, at *7*; and the choke fitting, at *12*. The space *a* between the strainers is filled with curled hair.

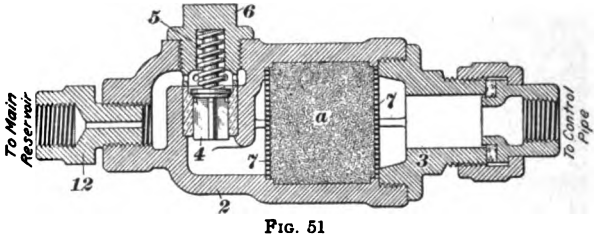

FIG. 51

One end of the device is connected to the control pipe, and the other end to the main-reservoir pipe. In case of trouble with the compressor on a car, the check-valve allows air to pass slowly from the control pipe to the main-reservoir pipe through the small hole in the choke fitting, but it does not allow air to pass in the reverse direction.

TRAIN CONTROL

77. Since, with the exception of the electric control device, the A. M. M. E. system is exactly the same as the A. M. M. system, all the instructions given for the control of the A. M. M. system apply also to the A. M. M. E. system. On account of the electric feature, however, further instruction is necessary.

It should always be remembered that in electric-traction service the most important thing is not to block the road; consequently, when a train is disabled, the trouble should be remedied in the quickest way possible, so that the train can be moved to the end of the division and not delay traffic. Permanent repairs can then be made as desired.

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78. Burst Hose. —In the event of a hose bursting, close the cut-out cock on each side of the burst hose and release the brake back of it by placing one of the brake valves in release position. When this is done, place one of the trainmen in charge of the brake at the rear of the train, so that if the motorman whistles for brakes, the trainman can apply the brake back of the burst hose by means of the brake valve or by opening a conductor's valve.

79. Brake Sticks After a Pneumatic Service Application.—In the event of the brake sticking, make a 10-pound brake-pipe reduction and place the handle of the brake valve in release position. This should release the brake. If it does not, or if the brake in question causes further trouble, close the double cut-out cock so as to cut the brake out of service. Then block the bleed cock of the auxiliary reservoir, open the brake valve, and proceed with the train.

80. Making Time.—To make time, no time should be lost either in accelerating or retarding the train. Therefore, to gain time in decelerating the train, apply the brakes at once as hard as the speed will warrant and graduate the brake off so as to make the stop at the proper point. For high speeds, a full application should be made at once; for lower speeds, the amount of the application will depend on the rate of speed.

81. To Handle Trains Smoothly.—To make smooth stops, make as heavy an application as is consistent with the speed, and soon enough to stop the train a car length or so short of the stopping point if the brake is held on. As the stopping point is approached, graduate the brake-cylinder pressure down so that there will be only a few pounds of brake-cylinder pressure remaining when the train comes to a standstill.

With a train on the level, release the brake as soon as the train stops. If the train is on a grade, hold the brake applied until the signal to start is given and then release. On account of the small amount of brake-cylinder pressure, the brake can be released promptly and the train started without loss of time.

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82. Emergency Applications.— If it is necessary to make an emergency application of the brakes while they are under electric control, move the brake valve instantly to pneumatic emergency position and leave it there until the train is stopped or the danger is past.

TYPE J ELECTRIC PUMP GOVERNOR

DESCRIPTION

83. The **type J electric pump governor** is installed on electric locomotives or trains in connection with direct-current or a single-phase alternating-current motor used to drive an air compressor. The governor automatically controls the operation of the air compressor between predetermined minimum and maximum air pressures in the main reservoir of the braking system. The air compressor supplies the main reservoir with air under pressure. If the pressure falls below a predetermined value, the governor closes a switch and starts the compressor motor. The

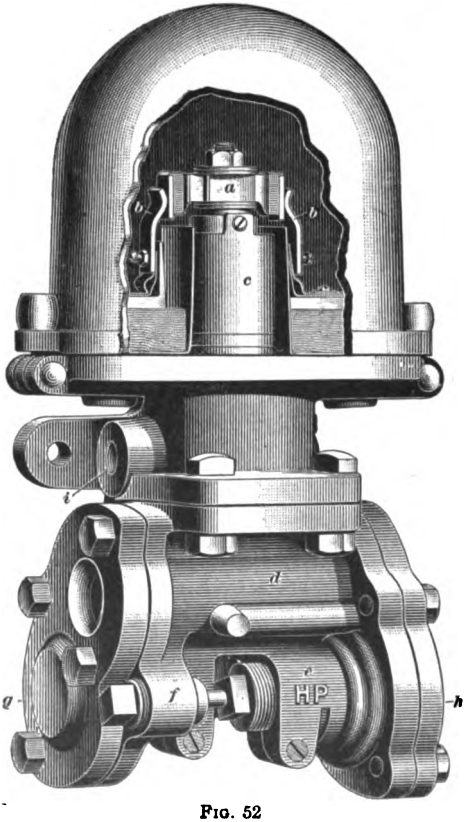

FIG. 52

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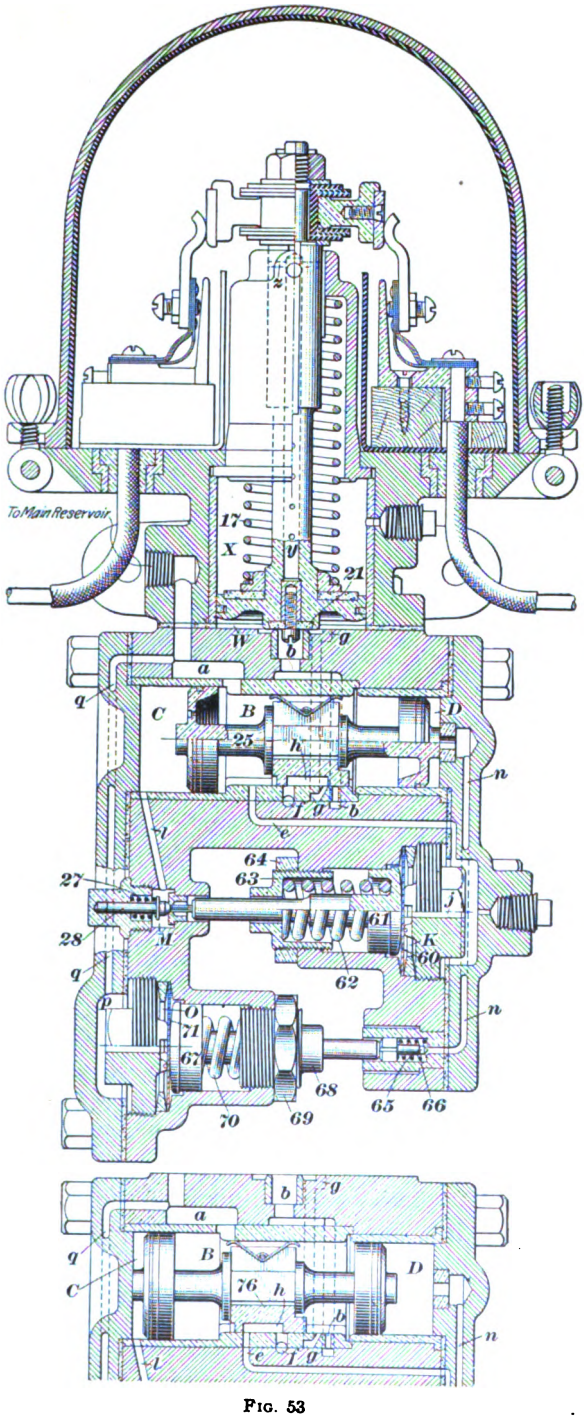

FIG. 53

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air pressure in the main reservoir then increases, and when at the desired maximum value, the governor opens the switch and stops the compressor motor.

84. The governor consists of a switch and the pneumatic apparatus necessary to open and close the switch. The electric circuit to the compressor motor is made or broken by this switch. In Fig. 52 is shown the type J governor with the switch cover broken away, exposing the switch spider *a*, the two contact fingers *b*, and the cylinders *c*, in which the switch piston and the piston rod move. The cylinder *d* contains a double piston and its attached slide valve. The regulating spring for the cutting-out mechanism is contained in cylinder *e*, and at *f* is shown the cutting-out regulating valve. The regulating spring for the cutting-in mechanism is contained in cylinder *g*, and the cutting-in regulating valve *h* (not shown in the sketch) is in line with *g* at the back of the governor. The main-reservoir connection is shown at *i*.

OPERATION

85. In Fig. 53, the governor is shown diagrammatically in order to illustrate more clearly the different parts of the device and their connections. The parts indicated in Fig. 52, however, may be recognized in Fig. 53. The parts shown in Fig. 53 are in the positions taken when the main-reservoir pressure has caused the governor to go to its cut-in position; the switch is then closed, and the motor is operating the compressor.

86. The cutting-out operation will be described first. Air from the main reservoir enters the governor at the connection marked *To Main Reservoir* and flows through passage *a* to the space *B* between the two pistons of the double piston *25*. The pressure of the air in space *B*, therefore, is the same as that of the air in the main reservoir. From space *B* the air flows through ports *e* and *j* to the space *K* on the face of the diaphragm *60*. One end of the spindle *61* is held against the diaphragm by the regulating spring *62*, and

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the other end of the spindle presses against the cutting-out regulating valve *28*.

When the reservoir pressure is less than the cutting-out value for which spring *62* is adjusted, the spindle is held to the right by the spring, so that valve *28* is seated by the pressure of its spring *27*. When the maximum reservoir pressure is obtained, the air pressure in *K* forces the diaphragm and spindle to move slightly to the left. The stem at the left end of the spindle then forces the cutting-out regulating valve from its seat.

The air in chamber *C* can now flow through port *l*, space *M*, and the slightly opened valve to the atmosphere, past the stem of the spindle. The air pressure in chamber *C*, which on account of leakage of air from chamber *B* through a small leakage port in the piston, was approximately at the same pressure as the air in chamber *B*, is now reduced. Air exhausts from chamber *C* much faster than air enters it from chamber *B* through the small leakage port in the piston. The pressures on each side of the small piston on the right of the double piston are balanced because of leakage past this piston, and the pressure on the right of the large piston is now much higher than that in chamber *C* on the left of this piston. The excess pressure now forces the double piston and its attached slide valve to the left into cut-out position, as shown in the detail sketch at the bottom of Fig. 53.

The slide valve *76* (detail sketch) uncovers port *b*, and air at reservoir pressure now flows through passage *a*, space *B*, and passage *b* to the piston seat *21*. Only a small portion of the piston is exposed to the action of this air, and though the piston is raised but slightly by it, the pressure of the spring is partly overcome; thus, when further movement of the slide valve uncovers port *g*, air at reservoir pressure flows through passage *g* to space *W* under the switch piston, causing the piston to move up rapidly and thus make a quick break at the switch.

The movement of the piston compresses the air above it, and this air is forced to the atmosphere through ports *y* and *z* in the hollow piston rod. The air coming from chamber *X*

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through ports *s* acts as a pneumatic-arc blow-out at the instant the circuit is broken.

The cavity *h* in the slide valve now connects port *e* to the exhaust port *f* and to the atmosphere. The pressure on the diaphragm *60* is relieved and the regulating valve *28* is seated, closing the exhaust of chamber *C*. The air pressures of chambers *B* and *C* soon balance on account of the flow of air through the leakage port in the large piston. The double piston remains in the cut-out position until the air pressure in the reservoir falls to minimum value, when the governor acts to cut in, or close, the circuit.

87. The action of the governor when cutting in is as follows: Air at main-reservoir pressure flows from the port *a* through ports *q* and *p* into the space *O* on the face of diaphragm *71*. One end of the spindle *67* is held against the diaphragm by the cutting-in regulating spring *70*. The stem at the other end of the spindle presses against the cutting-in regulating valve *65*. If the reservoir air pressure is sufficiently high to overcome the pressure of the regulating spring *70*, the spindle will keep the valve *65* seated and the port *n* closed.

When the air pressure falls below the desired minimum value, the pressure of the spring *70* overcomes the effect of the air pressure of the reservoir, and the diaphragm *71* and the spindle *67* are moved slightly toward the left. The regulating-valve spring *66* now unseats the valve *65* and uncovers the exhaust port *n*. The port *n* connects to chamber *D*, back of the smaller piston. The air pressure in chamber *D* is reduced, and as the air pressures on each side of the larger piston are balanced, and the air pressure in chamber *B* is now higher than that in chamber *D*, the double piston and its slide valve are moved to the right to the cut-in position, as indicated in the complete sketch of Fig. 53. The air from cylinder *W* now exhausts through port *g*, cavity *h*, and exhaust port *f* to the atmosphere, and piston spring *17* forces the piston down and closes the switch.

The motor starts and increases the reservoir air pressure until the desired maximum value is reached, when the governor

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cuts out the motor, as previously described. When the double piston is in the cut-in position, a projecting boss on the outside surface of the smaller piston closes port *n*, thus cutting out the exhaust passage of chamber *D*. The air pressures of chambers *B* and *D* soon equalize on account of leakage of air around the small piston, and the double piston remains in cut-in position until the governor acts to cut out the motor.

ADJUSTMENT

88. The cutting-in and the cutting-out air pressures are adjusted by means of the regulating nuts *68* and *63*, Fig. 53. The method recommended for regulating the governor when assembling or after repairs is as follows: Relieve the pressures of both regulating springs by unscrewing nuts *68* and *63*. Valve *65* will now be open because there is no air pressure in the space *O*, and spindle *67* is moved to the left by spring *70*, thus allowing spring *66* to open valve *65*. Valve *28* is closed. The switch is closed because there is no air pressure to open it. Chamber *D* is connected to the atmosphere through valve *65*, while the exhaust passage of chamber *C* is closed. Very soon after the compressor starts, the air pressure acting on the diaphragms is sufficient to close valve *65* and open valve *28*. The governor then moves to cut-out position and stops the compressor.

Screw in nut *63* until spring *62* is under considerable compression. This action closes valve *28*. Screw in nut *68* slowly until valve *65* is unseated, the governor cuts in and the compressor starts.

Watch the air gauge as the air pressure increases, and note the air-pressure value at which the governor cuts out. If the value is lower than is desired, screw in nut *63*; if too high, screw out nut *63*. Bleed the main reservoir, or, if the main-reservoir pressure is below the desired cutting-in point, screw in on nut *68* so as to increase the pressure on spring *70*, and to cause the governor to cut in. Again note the pressure at which the governor cuts out and make the further adjustment of the regulating nut *63* that is necessary to obtain the desired cutting-out pressure.

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After the adjustment for the cutting-out point is made, bleed the main reservoir slowly until the governor cuts in. Adjust the cutting-in point to that desired by screwing the regulating nut *68* in or out.

Regulating check-nuts *69* and *64* should then be tightened, and a final test should be made to see that no change in adjustment was made when the check-nuts were tightened.

In some forms of the governor, the end portions of each of the two cylinders containing the regulating springs are split and means are provided for clamping the regulating nuts within the split portions of the cylinders, as shown in Fig. 52. The check-nuts are then omitted.

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BRAKES
(PART 3)

NO. 14 E L LOCOMOTIVE BRAKE EQUIPMENT

GENERAL REMARKS

1. In principle and design, the **E L electric-locomotive brake equipment** is similar to the E T steam-locomotive brake equipment, a few changes having been made in the E L equipment to meet the requirements of construction and operation peculiar to the electric locomotive.

The construction of some of the parts of the E L equipment, and the operation of the brakes as a whole are somewhat different from that of the other types of brakes used on electrical equipment. The motor-driven air compressors, the main reservoirs, the air gauges, and the brake cylinders with their apparatus for transmitting the power to the brake shoes are practically the same as in the older equipment, but a new form of automatic and independent air-brake valve and a new slide-valve feed-valve replace the older forms. The distributing valve takes the place of the triple valves, auxiliary reservoirs, and high-speed reducing valves used on the steam locomotive. The reducing valve for the independent brake valve also acts as a reducing valve for the air-signaling system.

2. This new type of locomotive brake equipment can be applied to any electric locomotive, whether used in high-

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speed passenger service, in ordinary passenger service, in freight service, or in any kind of switching service. It has all the advantages of the older types and many other important advantages that were found by practical experience to be necessary in handling modern equipment. Brakes can be applied with either a graduated full service or an emergency application, the same as with the older forms of brake. The locomotive brake can be applied and released simultaneously with the brakes on the cars or independently of them, and can be released, either wholly or partly, at the will of the motorman. It is possible to release the train brakes and hold the locomotive brakes applied full force, thus, in freight service, tending to prevent the slack of the train running out and breaking the train in two when releasing the brakes at moderate speed. When double heading, the brakes on either locomotive can be applied or released by the motorman on that locomotive without affecting the other brakes. This is a valuable feature in making smooth, accurate stops and when working on grades. Also, as the supply of air for the locomotive brake cylinders is taken direct from the main reservoir, the locomotive brakes are prevented from leaking off as they do when the brake-cylinder supply is taken from the auxiliary reservoir.

Neither the length of brake-piston travel nor the brake-cylinder leakage affects the brake-cylinder pressure, and so long as the brake piston does not strike the non-pressure head of the brake cylinder, or the brake rigging does not catch something that will prevent the power exerted on the piston from being transmitted to the brake shoes, the locomotive brake will be applied with full pressure. If the brake is applied with the independent brake valve to prevent the locomotive from moving after being stopped, it will not leak off; and while standing on a grade, the locomotive brake can be applied independently to hold the train while the auxiliaries on the cars are being charged.

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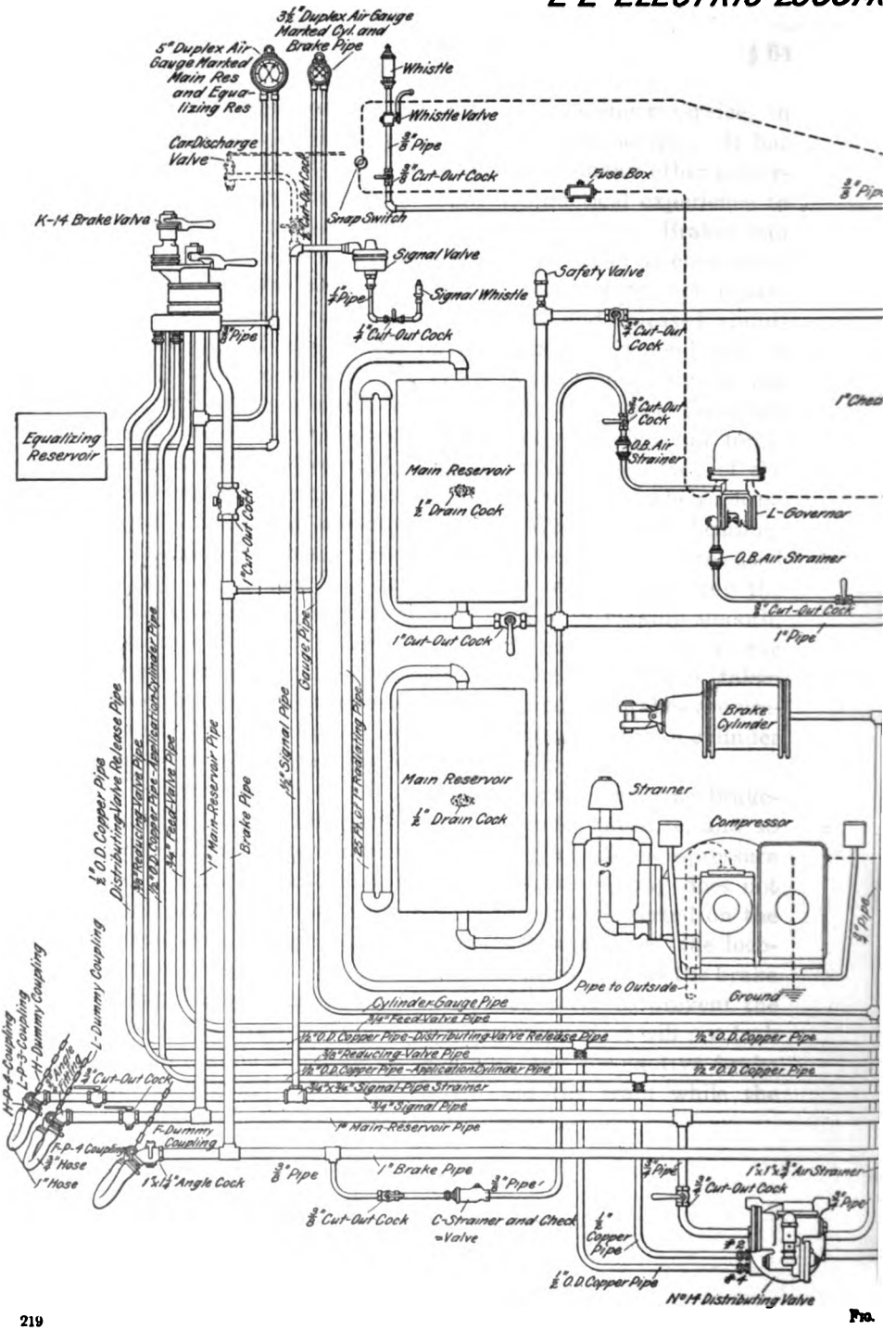

Fig.

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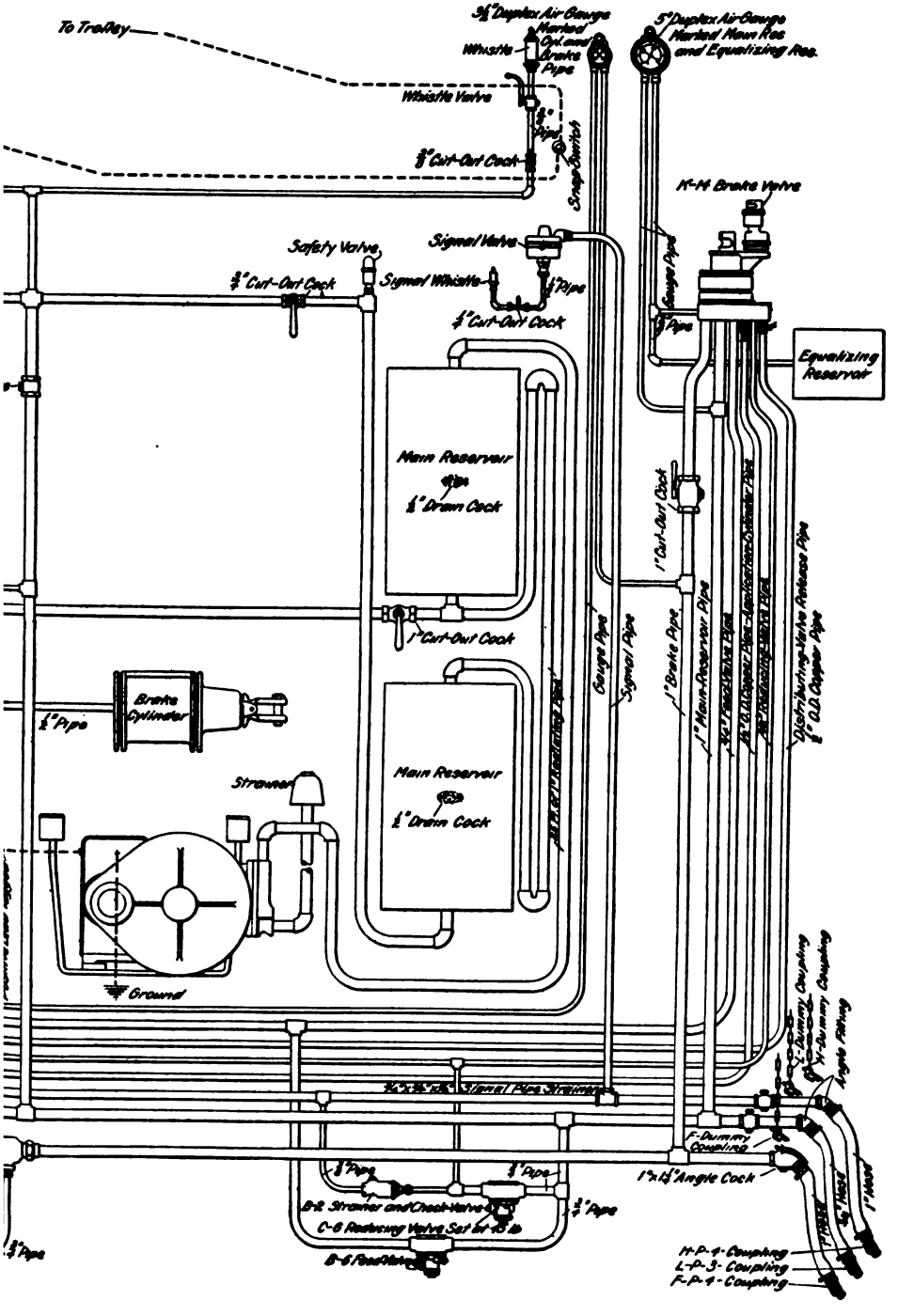
'VE BRAKE EQUIPMENT



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PIPE ARRANGEMENT

3. Fig. 1 shows the arrangement of the various valves, pipes, pipe connections, etc. of the No. 14 E L equipment. Air from the atmosphere enters at the strainers and is forced by the compressors through the discharge pipe and radiating pipes into the main reservoirs. Usually four main reservoirs are used in order to provide for sufficient compressed air with which to promptly release the brakes on the locomotive and train and recharge the system. These reservoirs and radiating pipes assist in cooling the compressed air, and the moisture, oil, or other foreign matter is deposited in the main reservoirs, where it can be drained off through the drain cocks. This insures the use of clean, dry air in the brake system.

Air from the main reservoir or its connections is supplied to the compressor governor; to the alarm whistle, situated at each end of the locomotive, a check-valve being placed in the main-reservoir pipe leading to the distributing valve and the automatic brake valves to prevent an overreduction of main-reservoir pressure from interfering with the automatic brakes when the alarm whistle is being used; to the distributing valve for use in the brake cylinders when the brakes are being applied; to the B-6 feed-valve, through which it is reduced to the pressure carried in the braking system; to the C-6 reducing valve, which reduces the pressure to 45 pounds to be used in the air-signaling system and by the independent brake valve; to the automatic brake valve to supply main-reservoir air to the chamber above the rotary; to the red hand of the larger duplex air gauge to show its pressure; and to the main-reservoir line cut-out cocks and hose at the ends of the locomotive. The main-reservoir supply pipe is extended through the locomotive and is provided with hose connections on each end, so that, when double heading, the main-reservoir systems of the locomotives can be connected and the supply from the compressors on both locomotives placed under the control of the motorman on the leading locomotive for use in recharging and maintaining the pressures on the train. The safety valves, shown in Fig. 1,

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connected to the main-reservoir pipe between the main reservoir and the main-reservoir cut-out cocks, are provided to guard against excessive main-reservoir pressure in case the governor becomes inoperative. The safety valves are set 10 pounds higher than the maximum main-reservoir pressure. Besides these, as many more connections may be made to the main reservoir as are required to operate other air-using devices, such as bell ringers, sanders, electropneumatic unit-switch control systems, etc. If a pressure lower than that in the main reservoir is desired to operate the devices, the pressure is reduced by passing the air through reducing valves.

The electric pump governor automatically controls the compressors between the predetermined minimum and maximum pressures. The cutting-in pressure is usually 15 pounds higher than the feed-valve pressure, and the cutting-out pressure is about 15 pounds higher than the cutting-in pressure.

4. A combination of two brake valves, the automatic and independent, with separate handles, mounted on a single pipe bracket, is placed at each end of the locomotive. The brake pipe leads from the automatic brake valves throughout the length of the locomotive and train, and it has a branch in the part on the locomotive that leads to the distributing valve and another from below the cut-out cock under the brake valve to the black hand of the small duplex air gauge. With this arrangement the black hand of this gauge will indicate the brake-pipe pressure whether the cut-out cock is open or closed, and the part of the brake pipe on each car has a branch leading to the triple valve. By means of this communication, the motorman can operate the brakes as desired, by the use of the automatic brake valve.

Fig. 1 also shows the double arrangement of the parts, which is necessary in order that the brakes may be properly handled from either end of the locomotive. Any or all of these duplicate parts may be cut out from the others when necessary by closing the cut-out cocks provided for that purpose. To cut out one of the compressors, the electric-circuit connection to it must be disconnected.

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5. The application-cylinder pipe leads from the brake-valve pipe bracket at each end of the locomotive to the application cylinder of the distributing valve. The distributing-valve release pipe extends from the distributing-valve exhaust to the brake-valve pipe bracket at each end of the locomotive. The feed-valve pipe leads from the B-6 feed-valve to the pipe bracket of the brake valve at each end of the locomotive.

The reducing-valve pipe leads from the C-6 reducing valve to the brake-valve pipe brackets and supplies air at a pressure of 45 pounds to the independent brake valve. An equalizing reservoir is placed at each end of the locomotive and is connected by a pipe to the space above the equalizing piston of the automatic brake valve. A branch from this pipe leads to the black hand of the large duplex air gauge, which indicates equalizing-reservoir pressure.

The brake-cylinder pipe leads from the distributing valve to the brake cylinders and has a branch leading to the red hand of the small duplex air gauge, placed at each end of the locomotive to indicate the brake-cylinder pressure. If brake cylinders are placed on the trucks, the brake-cylinder pipe is connected to the brake cylinders by means of branch pipes and hose connections, and a No. 8 double check-valve is added.

6. The C strainer and check-valve, together with the cut-out cock and piping from the brake pipe to the main-reservoir pipe, constitute the by-pass feature of the equipment. It is used when a dead locomotive or one with disabled air compressors is in a train, so that the supply of air for the distributing valve and brake cylinders of the dead locomotive can be taken from the supply in the brake pipe furnished by the other locomotive. In such a case, the brake-valve cut-out cocks in the brake pipe underneath the brake valves on the dead locomotive must be closed and the cut-out cock in the by-pass pipe opened. Then the strainer and check-valve will allow the brake-pipe air to pass slowly to the main reservoir of the dead locomotive to operate its brake, and it will prevent the air from returning to the brake

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pipe, which would interfere with the operation of the brakes on the train. When a dead locomotive is handled in this way, one set of main reservoirs should be cut out. When not used to supply air for the distributing valve in this manner, the cut-out cock in the by-pass pipe must be closed.

After having been reduced to a pressure of 45 pounds by the C-6 reducing valve, main-reservoir air passes into a pipe from which branches lead to the independent brake valve and by way of the B-2 strainer and check-valve to the air-signaling line. The air-signaling line on the locomotive has branch pipes leading to the signal valves at each end of the locomotive. The car discharge valves, by means of which reductions in the signal pipe are made, are connected to the signal line of the cars, and also to that on the locomotive when desired.

TYPE K-14 BRAKE VALVE

7. As previously mentioned, the K-14 brake valve is a combination of two brake valves, the *automatic* and the *independent*, with separate handles, mounted on a single pipe bracket. The automatic portion of the valve is modeled to a considerable extent on the principles embodied in previous styles of automatic brake valve, but is somewhat different in detail, as it not only performs all the functions of the other types but also those necessary to obtain all the desirable operating features of the No. 14 distributing valve. All pipe connections are made to the pipe bracket to which the brake valve is fastened, so that the valve can be removed for repairs or to replace it with another one without breaking any pipe connections.

In explaining the construction and operation of the K-14 brake valve, the automatic valve will be the first to be taken up.

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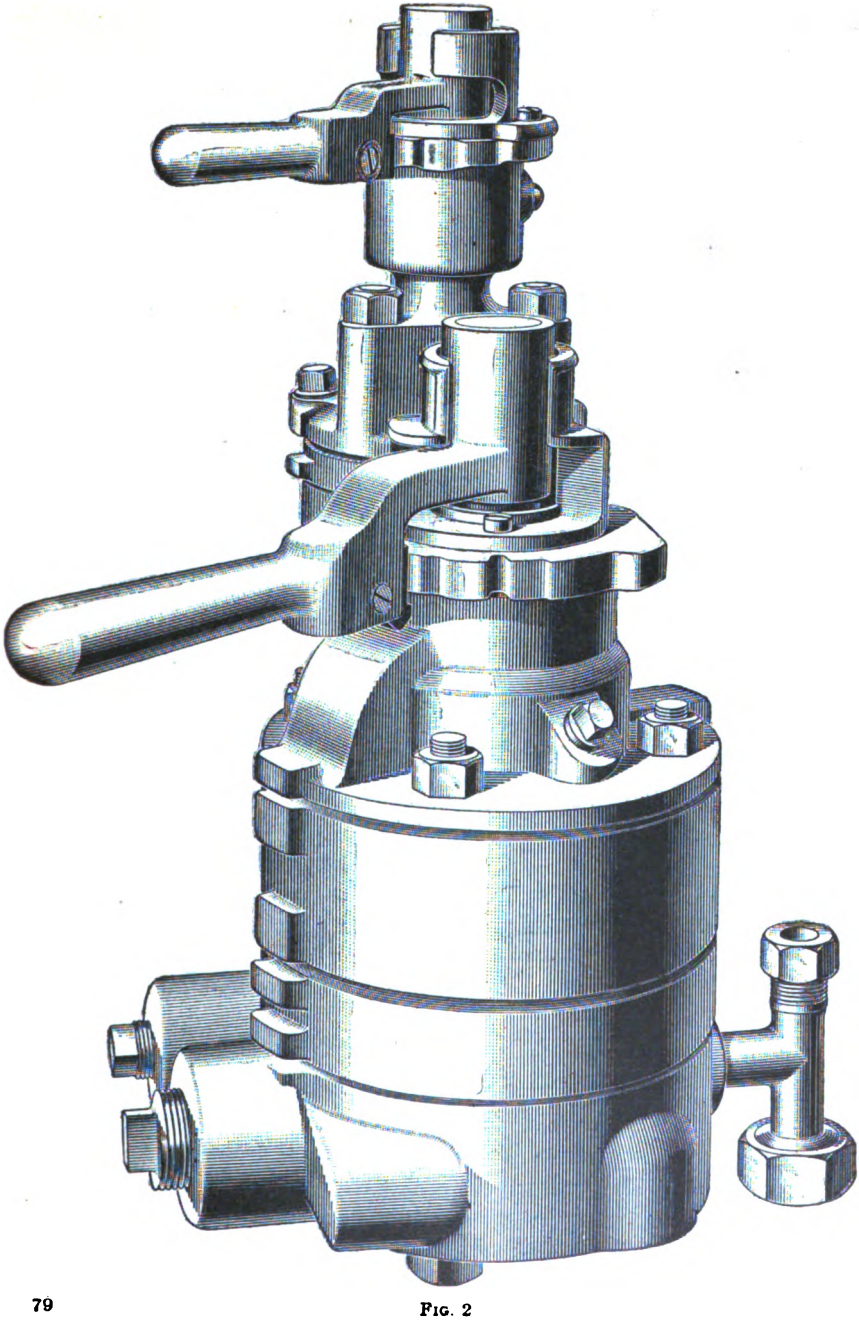

FIG. 2

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DESCRIPTION OF AUTOMATIC BRAKE VALVE

8. Fig. 2 shows the complete valve in a side view. The independent brake valve is shown mounted on a bracket somewhat above and back of the automatic brake valve.

Fig. 3 is a plan view of the top of the brake valve, showing the several positions of the handles. There are six positions of the automatic brake valve and five positions of the

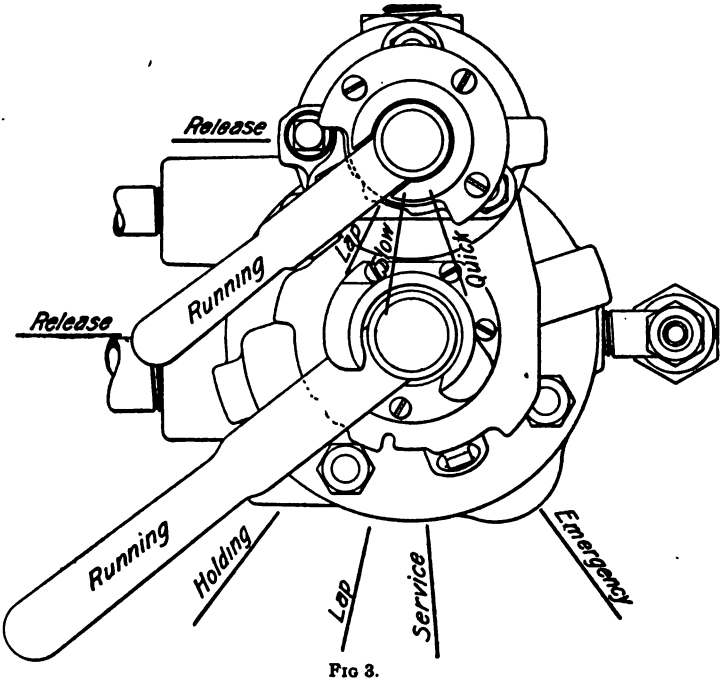

FIG 3.

independent brake valve. The purpose of each position will be given when explaining the operation of the brake valves.

Fig. 4 is a plan view of the automatic rotary-valve seat, showing the location of the various ports and cavities in the valve seat. The groove extending from port g' is for the purpose of forming a connection between this port and port d, Fig. 5 (a), in the rotary valve when the rotary valve is in emergency position.

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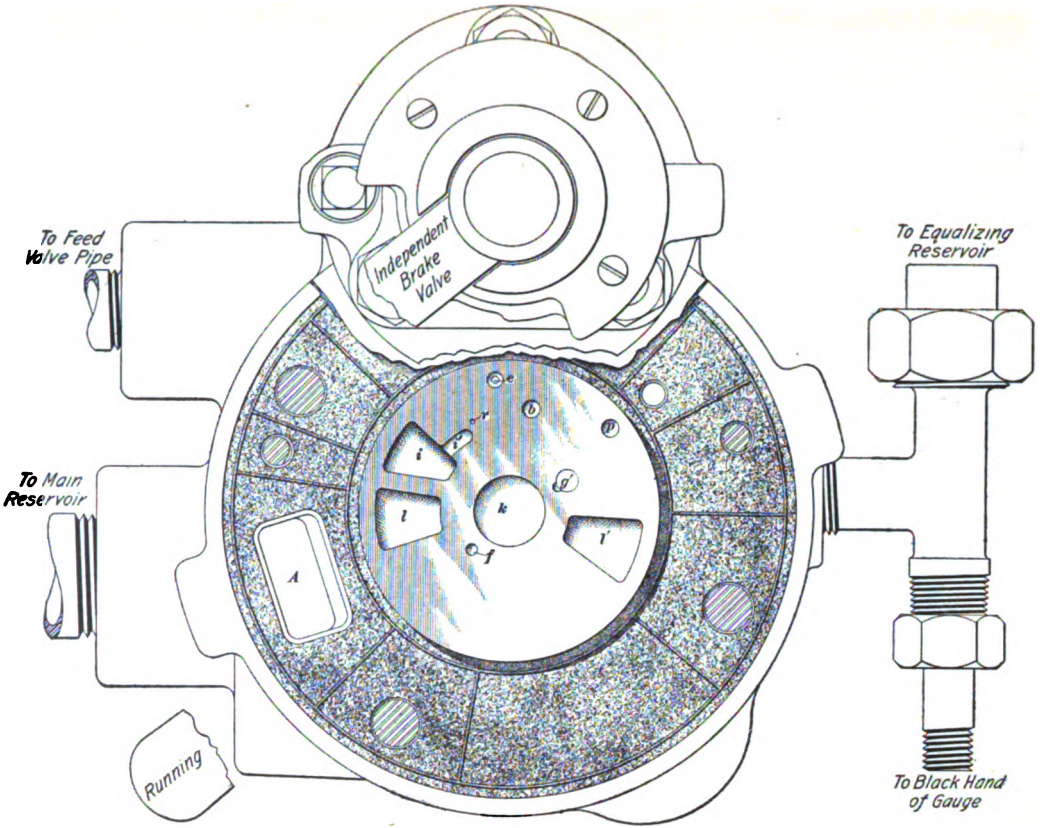

FIG. 4

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Fig. 5 (*a*) is a view of the face of the automatic rotary valve, showing the ports and cavities in the face of the valve.

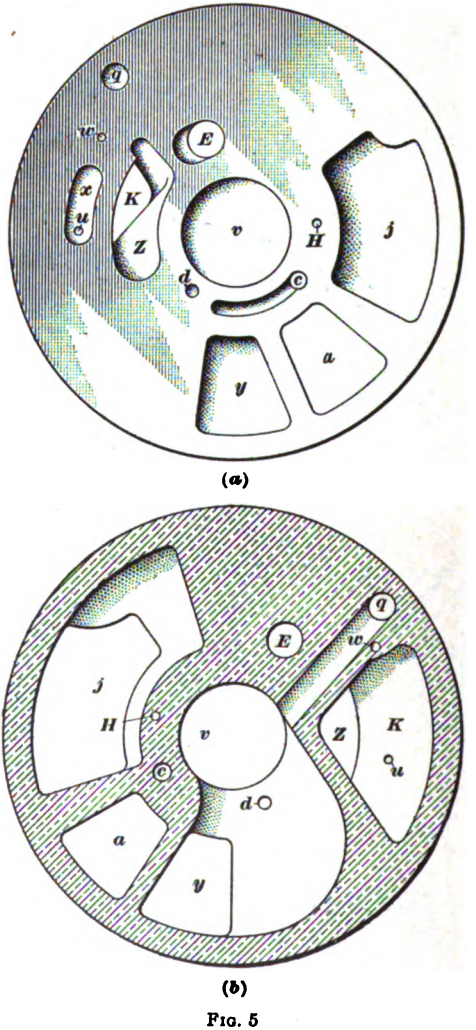

FIG. 5

Fig. 5 (*b*) shows a section of the automatic rotary valve, the top part being removed, and indicates the passages and cavities in the interior.

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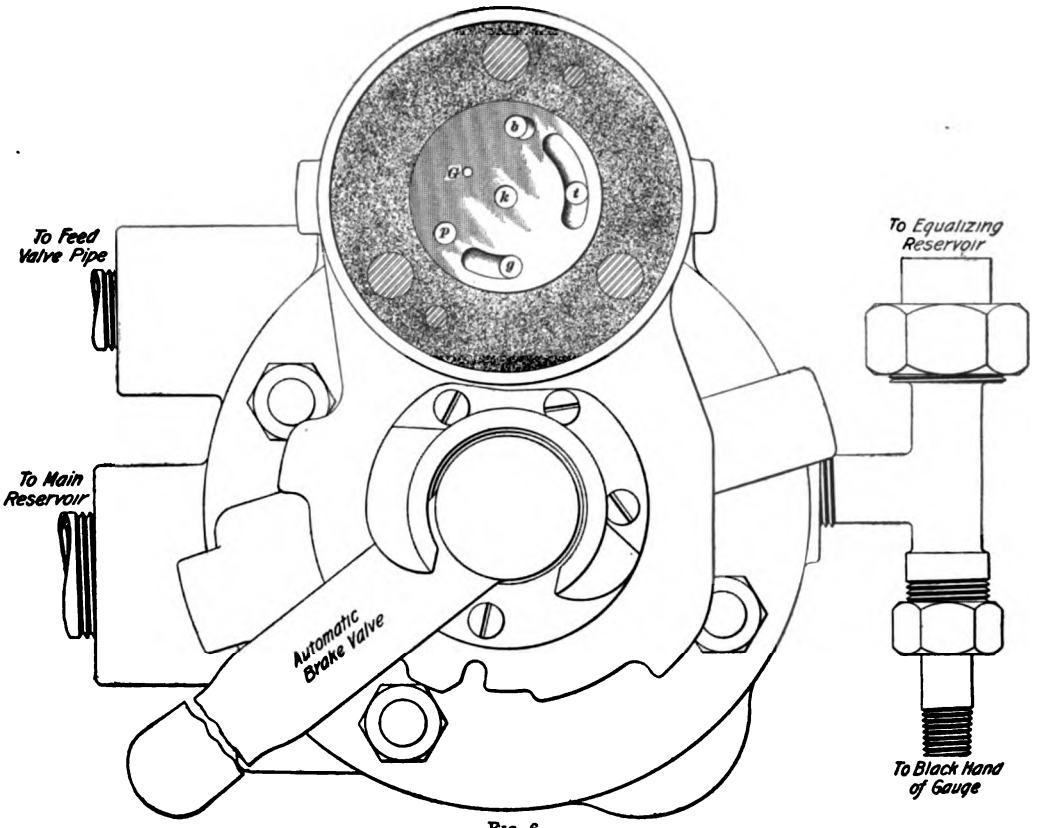

FIG. 6

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Fig. 6 is a plan of the rotary-valve seat in the independent brake valve, and Fig. 7 is a view of the face of the rotary valve of the independent brake valve.

9. Referring to Figs. 4 and 5, *k* is the exhaust port in the rotary-valve seat that leads directly to the atmosphere through the exhaust passage *Ex*, Fig. 8. The warning port *r* located in the rotary-valve seat leads into the exhaust passage *Ex*, and, when the brake valve is in release position, cavity *j* in the rotary valve connects port *i* with port *r*. Ports *l* and *l'* in the rotary-valve seat are connected to each other through a cored-out passage under the face of the rotary-valve seat; they are also connected through this passage to a passage in the pipe bracket that leads to the brake pipe. Port *i* connects with the feed-valve pipe and is connected with the brake-pipe port *l* by cavity *j* in the rotary valve, when the brake valve is in running and holding positions. Port *e* is the preliminary exhaust port and leads from the face of the rotary-valve seat to chamber *D*, above the equalizing piston. Port *g'* in the rotary-valve seat is the equalizing port and also passes from the face of the rotary-valve seat into chamber *D*. Port *E* extends directly through the rotary valve and connects with port *g'* when the brake valve is in release position, so that chamber *D* and the equalizing reservoir will be charged up very quickly in this position. Port *E* is also used to supply main-reservoir air to port *i* when the brake valve is in emergency position. Port *a* extends through the rotary valve and when the brake valve is in release position it registers with port *l* in the rotary-valve seat. This provides a large opening for main-reservoir air to pass to the brake pipe. The groove *Z* in the face of the rotary valve connects port *g'* with the brake-pipe port *l'* when the brake valve is in running or in holding position, so that in these positions the pressures can equalize in the equalizing reservoir and the brake pipe. Port *q* in the rotary valve connects the preliminary exhaust port *e* with the atmosphere through the exhaust cavity *v* and port *k* when the brake valve is in service position: port *q*

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also connects port *p* in the rotary-valve seat with the exhaust port *k* through cavity *v*, when the brake valve is in running position. Port *p* leads through the casting to port *p* in the independent brake valve (see Figs. 6 and 8); and, when connected with the exhaust port *k*, through port *q* and cavity *v*, allows the air that passes through the distributing-valve exhaust port to pass out to the atmosphere; air from the distributing-valve exhaust port can pass to the atmosphere through these ports only when the handles of the independent and the automatic brake valves are in running position. Port *y* in the face of the rotary valve is at all times connected by a cored passage with cavity *v* and is used in emergency position to discharge brake-pipe air from port *l'* directly to the atmosphere. Port *d* in the face of the rotary valve leads into the passage that connects port *y* with cavity *v*, Fig. 5 (*b*), and connects with the equalizing port *g'* when the brake valve is in emergency position so that the air in the equalizing reservoir can pass out to the atmosphere. Passage *A* leads from the main-reservoir connection of the pipe bracket to the chamber above the rotary valve, Fig. 8. The groove *Z* in the face of the rotary valve is connected to groove *x* in the face of the rotary valve through cavity *K* and port *u* so that when the brake valve is in emergency position the main-reservoir air passing through port *E* into port *i* and groove *i'* enters groove *Z* in the face of the rotary, then passes into groove *x* through cavity *K* and port *u* and out through port *b* in the rotary-valve seat to the application cylinder of the distributing valve.

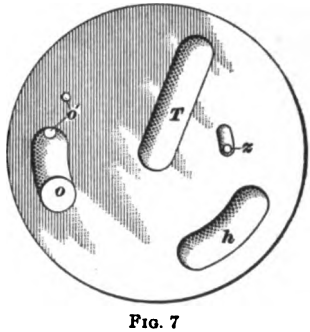

FIG. 7

Port *w* in the rotary valve registers with port *b* in the rotary-valve seat when the rotary valve is in service position. This allows main-reservoir air from above the rotary valve to pass into the application-cylinder pipe and assist in filling this pipe so as to obtain the desired application-cylinder

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pressure during service applications. As the application-cylinder pipe extends from the distributing valve to the brake valves at each end of the locomotive, and as the volume of this pipe must be added to the volume of the application cylinder, it will be seen that if all the air entering the application cylinder and application-cylinder pipe were taken from the pressure chamber in the distributing valve, the pressure in the application cylinder would not be raised to the desired amount with a given brake-pipe reduction. Port *w* also registers with port *l'* when the rotary valve is in release position but this connection is not required to perform any function.

Ports *c* and *H* in the rotary valve and port *f* in its seat are put in the K-14 brake valve only to provide for the use of duplex main-reservoir regulation on electric locomotives should it be desired later, but with the No. 14 equipment this system of regulation is not used, hence the ports *c*, *H*, and *f* perform no function in the operation of this equipment, and any further explanation of these ports will be unnecessary.

OPERATION OF AUTOMATIC BRAKE VALVE

10. As it is impossible to section the K-14 brake valve so as to show the movable parts, ports, and passages on one plane, a series of conventional views are shown in Figs. 8 to 17, inclusive. However, it should be borne in mind that these conventional views are given to help explain the operation of the brake valve and simplify the tracing of the flow of the air through it, not to represent its actual appearance. The various positions of the rotary-valve handle are shown in Fig. 3, which is a view of the top of the K-14 brake valve. The K-14 brake valve has in addition to the five positions of the older forms of brake valve, a new position called *holding position*, that comes between running and lap positions. This position is used in connection with the distributing valve to hold the locomotive brakes applied or graduate their release with the automatic brake valve, when the train brakes are being released. The different positions

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of the automatic brake-valve handle are *release*, *running*, *holding*, *lap*, *service*, and *emergency* positions. When describing the operation of the brake valve these positions will be taken up in their regular order.

11. Release Position.—The purpose of the release position is to provide a large direct passage for main-reservoir air to flow rapidly into the brake pipe to release and recharge

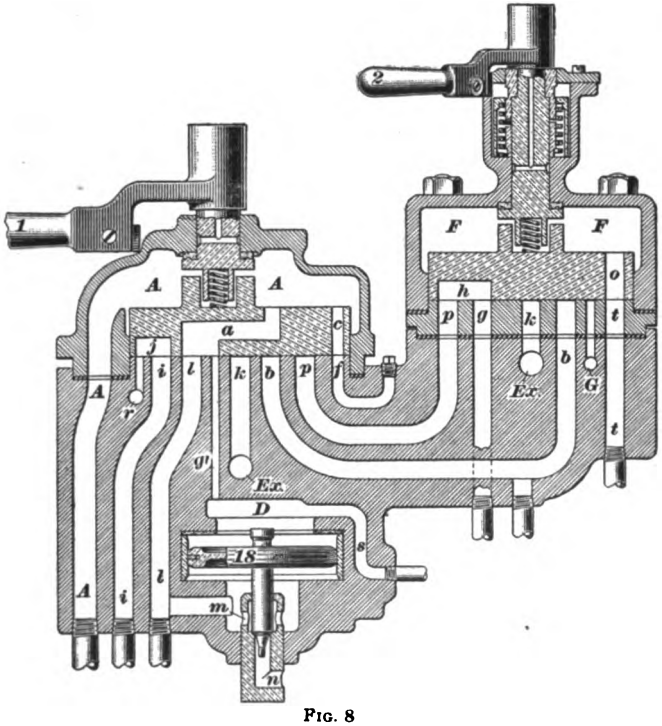

FIG. 8

the train brakes quickly, without releasing the locomotive brakes, if they are applied. Main-reservoir air at full pressure enters the brake valve at the main-reservoir pipe connection on the pipe bracket, passes up through passage *A A* in the sections of the brake-valve body to the chamber *A* over the rotary valve, Fig. 8, thence through the large supply port *a* in the rotary valve into port *l* in its seat, then through

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the cored passage in the rotary-valve seat to port *l'*, Fig. 4, and down through passage *l l*, in the sections of the valve body, to the brake-pipe connection on the pipe bracket, thus charging the brake pipe from the main reservoir direct. Port *w* in the rotary valve, Fig. 5, registers with port *l'* in the rotary-valve seat, Fig. 4, and allows air from above the rotary valve to pass in a small volume into the brake pipe, but this connection is not required to perform any function. Port *E* in the rotary valve, Fig. 5, also registers with the equalizing port *g'* in the rotary-valve seat, Fig. 4, so that main-reservoir air passes through ports *E* and *g'* to the chamber *D* above the equalizing piston *18*. This builds up the pressure in chamber *D* with that in the brake pipe so that the piston *18* does not rise and cause a discharge of air at the brake-pipe exhaust when releasing the brakes on a short train. Air passing through these ports can also pass to the equalizing reservoir and black hand of the large duplex air gauge so that the equalizing reservoir charges up at the same rate as chamber *D*, and the black hand of the large duplex air gauge registers the pressure in these places. Cavity *j* in the rotary valve connects port *i* and the warning port *r* in the rotary-valve seat, and allows air at feed-valve pressure to pass from port *i* through cavity *j*, port *r*, and the exhaust opening *Ex* to the atmosphere. The air escaping through these ports makes sufficient noise to attract the motorman's attention to the fact that the brake valve is in release position so that he will not leave it there too long and overcharge the brake pipe. The feed-valve cannot control the brake-pipe pressure when the brake valve is in release position; consequently, if the brake valve is left in release position too long, the brake pipe and the auxiliaries on the cars will be charged up to the pressure in the main reservoir, and if the brake valve is then moved to running or to holding position the brakes will be apt to creep on, especially if the brake-pipe pressure is reduced by leaks. With the brake valve in release position, port *q* in the rotary valve does not connect with port *p* in the rotary-valve seat, and port *p* being closed, air from the distributing-valve exhaust cannot escape through the automatic brake

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valve; consequently, the locomotive brakes will be held on, unless the independent brake valve is moved to release position. Port *p* is closed at all times except when the brake valve is in running position, and port *b* is closed at all times except when the brake valve is in service or in emergency position.

12. Running Position.—Running position, shown in Fig. 9, is the position in which the handle should be carried

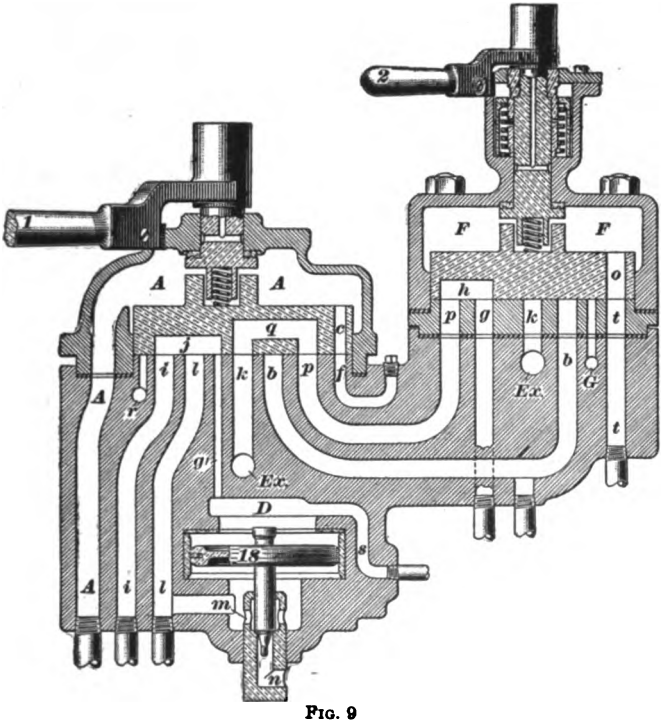

FIG. 9

when the brake system is charged and the brakes are not being operated; also, it is used to release the locomotive brakes through the automatic brake valve. In running position, air from the main reservoir cannot pass directly into the brake pipe nor through ports *E* and *g'*, Figs. 4 and 5, since port *a* in the rotary valve does not connect with port *l*

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in the face of the rotary-valve seat, and port *E* of the rotary valve is moved away from port *g'* in the rotary-valve seat. Also cavity *j* is moved away from the warning port *r* so that no air passes through port *r*. Cavity *j* in the rotary valve connects port *i* with port *l* in the face of the rotary-valve seat, so that air at feed-valve pressure entering the brake valve at the feed-valve connection on the pipe bracket, can flow through port *i*, cavity *j*, port *l*, thence through the cored-out passage in the rotary-valve seat into port *l'*, Fig. 4, and the passage *l l* to the brake pipe. These ports and passages afford a large direct opening from the feed-valve pipe to the brake pipe, so that the brake pipe will charge up quite rapidly to the pressure for which the feed-valve is adjusted, but no higher, and the excess pressure will be maintained in the main reservoir. Groove *Z* in the rotary valve, Fig. 5, now connects ports *l'* and *g'* in the face of the rotary-valve seat. This allows brake-pipe air to pass through port *l'*, groove *Z*, Fig. 5, and port *g'* to chamber *D* above the equalizing piston and to the equalizing reservoir, thus keeping the pressure above the equalizing piston equal to that below it. Brake-pipe air can also go to the black hand of the large duplex gauge; hence, in running position, the black hand of this gauge will register brake-pipe pressure as well as equalizing-reservoir pressure. Port *q* in the rotary valve now registers with port *p* in the face of the rotary-valve seat and air from the distributing-valve exhaust passing through the distributing-valve release pipe, port *g*, cavity *h*, and port *p* in the independent brake valve and the passage *p* in the casting to the automatic brake valve, can pass out to the atmosphere through ports *p* and *q*, cavity *v*, Fig. 5, port *k*, and the exhaust port *Ex*. The independent brake valve must be in running position also, and the distributing valve in release position in order to allow the air in the application chamber of the distributing valve to pass to the atmosphere through ports *p* and *q* in the automatic brake valve.

When making a two-application stop, it may be necessary to place the brake valve in running position for a few seconds

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to release the locomotive brakes when releasing the train brakes. Experience will soon show this point in making an easy and accurate stop with the No. 14 equipment.

13. Holding Position.—Holding position comes between running and lap positions and is shown in Fig. 10. It is so named because, with the brake valve in holding position, the locomotive brakes can be held applied by the

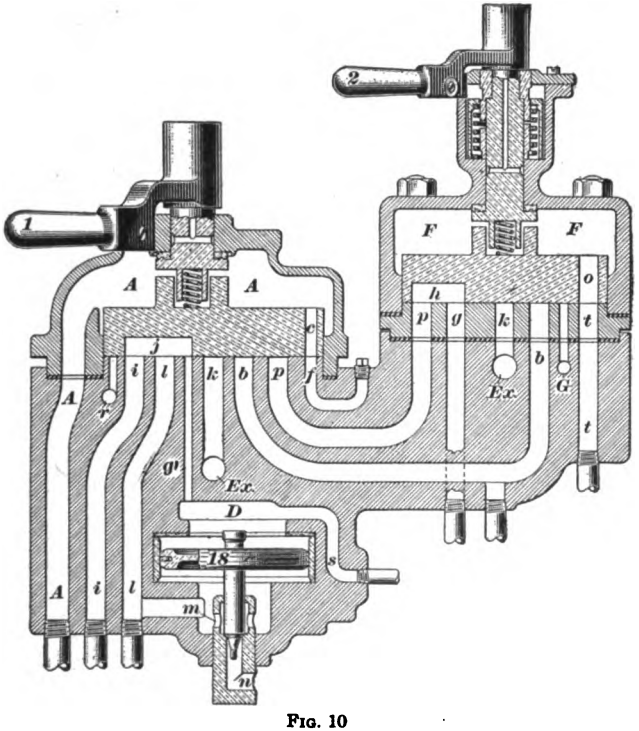

FIG. 10

automatic brake valve, with the independent brake valve in running position, while the train brakes are being released and recharged. Port *q* in the rotary valve, Fig. 5, is moved away from port *p* in the rotary-valve seat and the latter is closed by the rotary valve so that no air can escape from the distributing-valve exhaust through the automatic brake valve. This holds the air in the application cylinder of the

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distributing valve, and the locomotive brake, if applied, remains so. Cavity *j* in the rotary valve still connects port *i* with port *l*, so that air at feed-valve pressure flows through port *i*, cavity *j*, and port *l* to the brake pipe. Groove *Z* in the face of the rotary valve, Fig. 5, still forms a connection between ports *l'* and *g'* in the face of the rotary-valve seat, Fig. 4, so that the pressures on both sides of the equalizing piston are kept equal. The only difference between running and holding positions is that, in running position, port *p* in the rotary-valve seat is open to the exhaust and in holding position it is closed. In either position the train brakes are released and recharged.

14. Lap Position.—In lap position, Fig. 11, all ports connecting the main reservoir, brake pipe, equalizing reservoir, and the atmosphere with each other are closed. Port *p* in the rotary-valve seat is covered by the rotary valve, which prevents air escaping from the distributing-valve exhaust through the automatic brake valve.

The normal use of lap position is to blank all ports at the rotary valve between the reductions of brake-pipe pressure during a service application of the brakes, as well as to blank the ports in case of the train breaking in two, a burst hose, or when the conductor's valve or an angle cock has been opened.

15. Service Position.—Service position, which is shown in Fig. 12, is used to make a gradual service application of the brakes. When the brake-valve handle is moved to service position, port *q* in the rotary valve, Fig. 5, registers with port *e* in the rotary-valve seat so that air from the equalizing reservoir and chamber *D* above the equalizing piston *18* can escape gradually through the restricted opening in port *e*, Fig. 4, into port *q*, thence to cavity *v*, and out to the atmosphere through port *k* and the exhaust opening *Ex*. The equalizing reservoir with a capacity of about 800 cubic inches is connected to chamber *D* above the equalizing piston *18* to increase the volume of this chamber so that a graduated reduction can be made. The discharge of air through ports *e*, *q*, cavity *v*, port *k*, and the exhaust open-

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ing *Ex* reduces the pressure in chamber *D* above the equalizing piston *18*, and the brake-pipe pressure below piston *18*, then being greater than that above it, forces piston *18* up; this, in turn, raises the brake-pipe exhaust valve, which is a part of the piston stem, and allows brake-pipe air to flow to the atmosphere through the brake-pipe exhaust ports *m* and *n*. The service-exhaust fitting, having a $\frac{9}{32}$-inch opening with

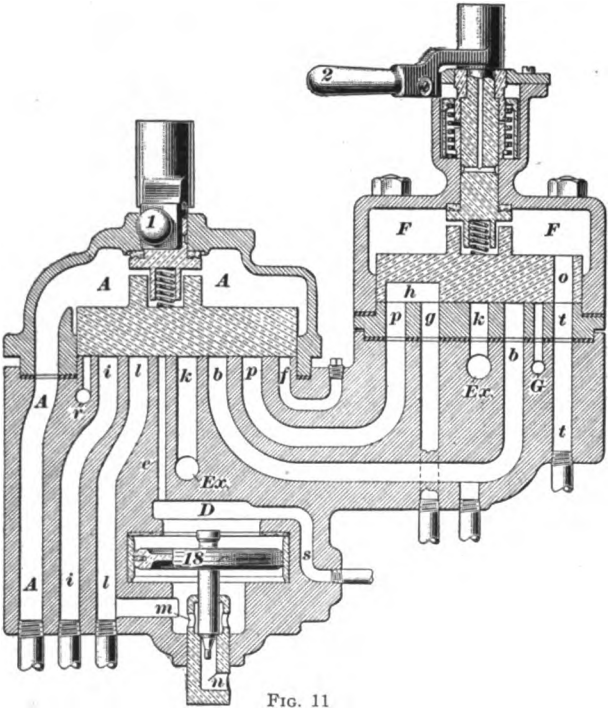

FIG. 11

a side outlet, is provided to graduate the flow of air from the brake-pipe exhaust. Also, when the rotary valve is in service position, port *w* in the rotary valve registers with port *b* in the face of the rotary-valve seat, thus allowing main-reservoir air to pass from chamber *A* through ports *w* and *b* into the application-cylinder pipe. As this pipe extends from the distributing valve to the brake valves at each end of the locomotive, considerable air is required to

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fill the pipe, hence air from above the rotary valve passes into the application-cylinder pipe to enable the air from the pressure chamber to raise the application-cylinder pressure the desired amount from a given reduction in brake-pipe pressure.

When a service application is to be made, the brake-valve handle should be moved to service position and left there

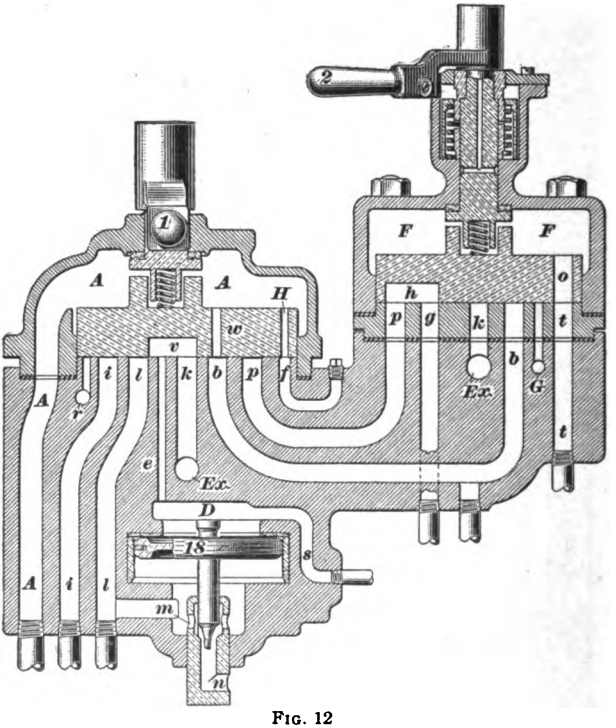

FIG. 12

until the equalizing-reservoir pressure has been reduced the desired amount, the reduction in equalizing-reservoir pressure being shown by the black hand of the large gauge; then move the handle back to lap position, which stops the flow of air from chamber *D* and the equalizing reservoir. Brake-pipe air will continue to flow from the brake-pipe exhaust port ***n*** until the pressure below piston *18* becomes slightly less than

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that above it, when the greater pressure above will move the equalizing piston *18* down and close the brake-pipe exhaust valve. With a very short train, the brake-pipe exhaust valve will close at about the same time that the brake-valve handle is moved back to lap position, but with a long train there is a larger volume of brake-pipe air, consequently the brake-pipe exhaust valve will remain open longer and the greater pressure above will slowly move the piston *18* down against the decreasing brake-pipe pressure, thus gradually and automatically closing the exhaust valve when brake-pipe pressure is slightly less than that in chamber *D* and the equalizing reservoir.

If the brake valve is again placed in service position, the equalizing-reservoir pressure will be reduced, and the equalizing piston *18* and the brake-pipe exhaust valve will automatically make the same reduction in brake-pipe pressure. In this manner the equalizing piston *18* and the exhaust valve automatically reduce brake-pipe pressure the same amount that the motorman reduces chamber-*D* and equalizing-reservoir pressure, regardless of whether the brake pipe is long or short.

16. Emergency Position. — Emergency position is shown in Fig. 13. When necessary to apply the brakes suddenly and with full force, the brake-valve handle is quickly moved to emergency position. Port *y* in the rotary valve now registers with port *l'* in the rotary-valve seat, Fig. 4, which allows brake-pipe air to pass through port *l'* into port *y*, thence through the cored passage leading from port *y* into cavity *v*, Fig. 5, and out through port *k* and the exhaust opening *Ex* to the atmosphere. These ports and passages provide a large opening from the brake pipe to the atmosphere, which causes a sudden and heavy reduction in brake-pipe pressure. This, in turn, operates the distributing valve and the triple valves quick action, so that all brakes are applied with a heavy cylinder pressure and in the quickest time possible. Port *E* in the rotary valve, Fig. 5, also registers with port *i* in the rotary

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valve seat, Fig. 4, and main-reservoir air passes into the feed-valve pipe. Groove *Z* in the face of the rotary valve, Fig. 5, connects with groove *i'* in the rotary-valve seat, Fig. 4, and groove *x* in the rotary valve registers with port *b* in the rotary-valve seat. This allows main-reservoir air to pass through port *E* into port *i* and through groove *i'* into groove *Z*, thence through cavity *K* and the maintaining

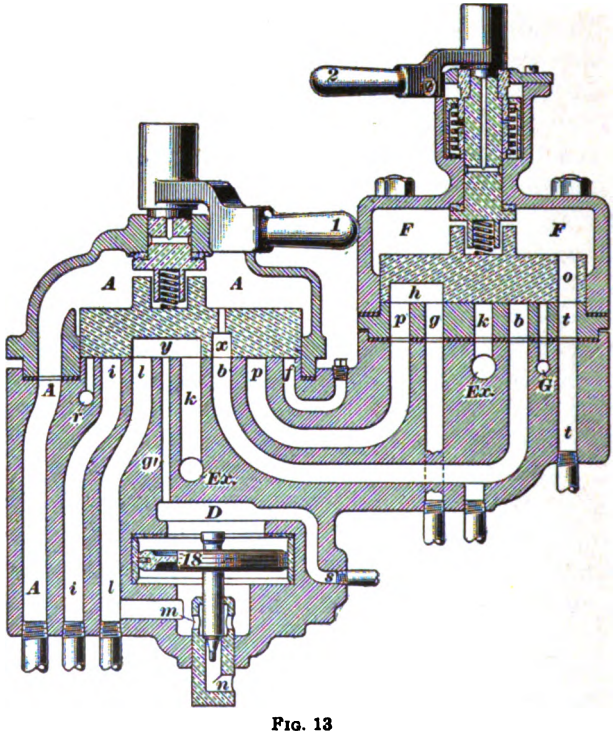

FIG. 13

port *u*, Fig. 5, groove *x*, port *b*, and the application-cylinder pipe to the application cylinder of the distributing valve. The opening through port *u* in the rotary valve is of such a size as will allow main-reservoir air to pass to the application cylinder of the distributing valve in about the same volume that it can pass from the application cylinder to the safety valve through the small port that connects cavity *q* and

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port *r* in the equalizing valve of the distributing valve [see Fig. 31 (*a*)]. This holds the application-cylinder pressure up to about 68 pounds. Port *d* in the face of the rotary valve, Fig. 5, also connects with port *g'* in the rotary-valve seat, Fig. 4. This allows chamber-*D* and equalizing-reservoir air to pass through ports *g'* and *d* into the passage leading from port *y* to cavity *v*, thence through cavity *v*, Fig. 5, port *k*, and the exhaust opening *Ex* to the atmosphere.

When double heading, the motorman on the following locomotive must keep the double-heading cock, in the brake pipe under the automatic brake valve, closed so as not to interfere with the proper handling of the train brakes from the leading locomotive. The automatic and independent brake valves on the following locomotives must also be carried in running position in order to give the leading motorman control of the distributing valves on the following locomotives.

DESCRIPTION OF INDEPENDENT BRAKE VALVE

17. The independent brake valve used with the No. 14 E L equipment takes the place of the straight-air brake valve used with the previous types of locomotive brake equipment. It not only performs all the functions of the former type of straight-air brake valves but in addition to this it enables the motorman to release the locomotive brakes when they have been applied and are being held on by the automatic brake valve. It also enables the motorman either to partly or fully apply or to release the locomotive brakes independently of the train brakes and regardless of the position of the automatic brake valve. This gives the motorman better control of the locomotive brakes, since in heavy-grade service he can prevent overheating of the driving wheels and assist the pressure-retaining valves in holding the train while the auxiliaries are being recharged. This is done by placing the independent brake valve in release position to keep the locomotive brakes released when the train brakes are applied, and moving it to application position to apply the locomotive brakes just before the train brakes are released. When

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double heading, the brake-valve cut-out cocks in the brake pipe must be closed, and the handles of both brake valves on one end of the following locomotive must be carried in running position in order to give the leading motorman control of the distributing valves on all locomotives. The motorman on the following locomotive can operate the independent brake valve to apply or release independently the brakes on that locomotive without interfering with the operation of the train brakes. In case the driving wheels become hot or slide, the brakes on the locomotive can be released at once by moving the independent brake valve to release position. The independent brake valve, like the previous type of straight-air brake valve, is a valuable adjunct to control the speed of the train, when it is slowed down, without the use of the train brakes; to hold the slack bunched when releasing at slow speed and thus avoid break-in-twos; to make close, accurate stops at platforms without the use of a sudden application of the train brakes; to hold the train while the train brakes are released after a stop on a grade; and in many other ways to promote smooth and safe handling of trains.

The independent brake valve receives air from the main reservoir through the C-6 reducing valve and reducing-valve pipe (see Fig. 1), so that the pressure in this brake valve will not exceed 45 pounds, the amount for which the reducing valve is adjusted. It is connected to the exhaust port of the distributing valve by the distributing-valve release pipe and to the K-14 automatic brake valve by passages in the casting. It is also connected to the application cylinder of the distributing valve through the application-cylinder pipe; a passage *b* in the casting, Fig. 13, connects with the passage leading from port *b* in the automatic brake valve to the application-cylinder pipe.

The various positions of the independent brake-valve handles are *release*, *running*, *lap*, *slow-application*, and *quick-application positions;* they come in the same relative order as on the automatic brake valve. This valve is attached to a bracket cast with the body of the automatic brake valve,

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where the motorman can easily reach it, and the handles of both brake valves point in the same direction when in similar positions, so as to avoid confusion in an emergency. These positions are shown in Fig. 3. The independent brake valve does not deliver air direct to the brake cylinders, but passes air into and out of the application cylinder of the distributing valve, which operates the application piston of the distributing valve to admit air to and exhaust it from the locomotive brake cylinders. The independent brake valve also controls the passage of air from the exhaust port of the distributing-valve application cylinder.

18. By referring to Fig. 6, it will be seen that there are six ports in the rotary-valve seat. Port *t* leads into the reducing-valve pipe, which supplies air from the C-6 reducing valve; port *b* leads through passage *b* in the casting to port *b* in the automatic brake valve, Fig. 4, and into the application-cylinder pipe that leads to the application cylinder of the distributing valve; port *g* leads into the distributing-valve release pipe, which is connected to the distributing-valve exhaust; port *p* leads through passage *p* in the casting to port *p* in the automatic brake valve; port *k* in the center of the valve seat is the exhaust port and leads directly to the atmosphere; port *G* is the warning port and leads to the atmosphere.

In the rotary valve (see Fig. 7), ports *o* and *z* pass directly through the valve. Cavity *T*, a groove extending from port *o*, and groove *h* are located in the face of the rotary valve. Port *o'* is also located in the face of the rotary valve and is connected with the groove extending from port *o* by a small passage in the interior of the rotary valve. The groove extending from port *o* in the rotary valve is at all times in communication with the groove in the rotary-valve seat that extends from port *t*, Fig. 6, so that air from the C-6 reducing valve passes through port *t*, groove, and port *o* to the space above the rotary valve, in all positions of the brake valve, and holds it on its seat. The groove extending from port *o* is also used in slow-application and quick-application

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positions. In slow-application position port *o'* in the face of the rotary valve registers with port *b* in the rotary-valve seat, so that air from port *t* passes through the groove extending from port *o*, the passage leading from it to port *o'*, thence through ports *o'* and *b* and the application-cylinder pipe to the application cylinder of the distributing valve. When the rotary valve is moved to quick-application position, the groove extending from port *o* is open to ports *t* and *b* its full size and the locomotive brakes are applied quickly. Port *s* in the rotary valve connects with port *G* in the rotary-valve seat when the brake valve is in release position and allows air to pass out through port *G* to the atmosphere. The sound of the escaping air calls the motorman's attention to the fact that the brake valve is in release position. The return spring, in the spring case around the rotary-valve key, is intended to return the handle of the brake valve from release to running position; consequently, if this spring is not too weak or broken, the valve will not remain in release position unless it is held there by the motorman. Cavity *T* in the rotary valve connects port *b* with the exhaust port *k* when the rotary valve is in release position. This allows air to pass from the application cylinder of the distributing valve, through port *b*, cavity *T*, and port *k* to the atmosphere, and releases the locomotive brakes. Groove *h* in the rotary valve is used only when the valve is in running position to form a connection between ports *g* and *p* in the rotary-valve seat, so that in running position air from the distributing-valve exhaust can pass through port *g*, groove *h*, and port and passage *p* to port *p* in the automatic brake valve, thence out to the atmosphere, provided the automatic brake valve is in running position.

OPERATION OF INDEPENDENT BRAKE VALVE

19. Release Position.—The release position, which is shown in Fig. 14, is to be used to release the locomotive brakes without regard to the position of either the automatic brake valve or the equalizing valve in the distributing valve;

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also, to release the locomotive brakes while the train brakes are being held on by the automatic brake valve, as well as to release the brakes when desired on the following locomotive of a double-header. When the valve is placed in release position, air from the application cylinder of the distributing valve passes through the application-cylinder pipe, port *b* in the rotary-valve seat, cavity *T* in the rotary valve, and the

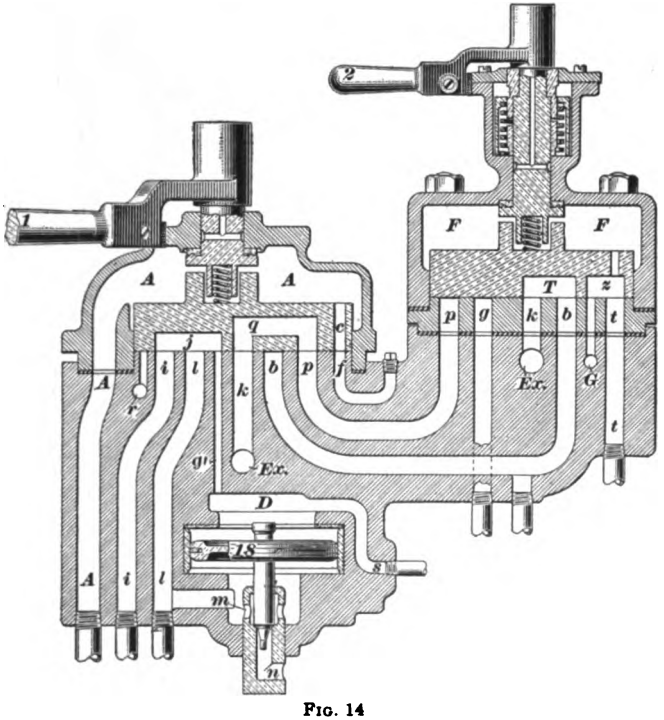

FIG. 14

exhaust port *k* in the rotary-valve seat to the atmosphere and releases the locomotive brakes. Also, in release position, port *z* in the rotary valve, registers with the warning port *G* in the rotary-valve seat and allows air to pass out to the atmosphere.

It is necessary to hold the handle of the independent brake valve in release position against the tension of the return

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spring, as otherwise this spring will automatically return the handle to running position.

20. Running Position.—The independent brake valve should be carried in running position at all times except when it is being used to operate the distributing valve to apply or release the locomotive brakes, or to keep the locomotive brakes applied. If it is carried in any other than running

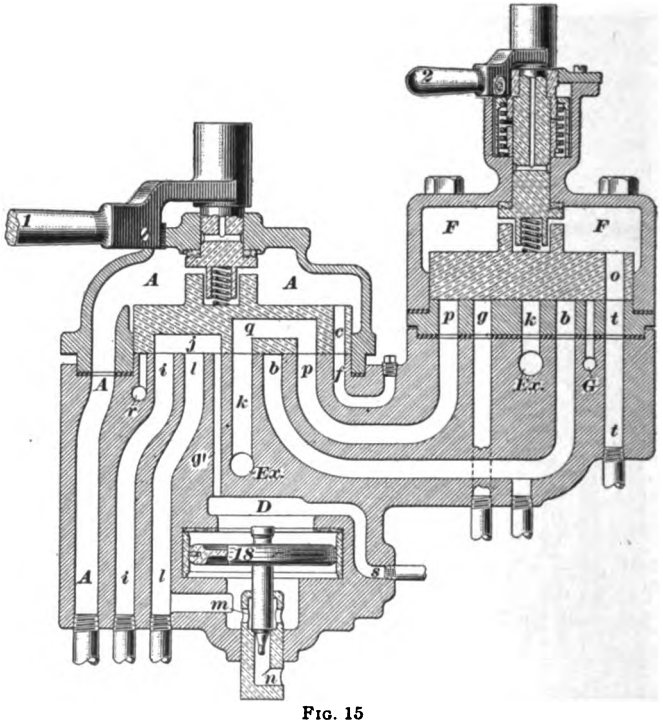

FIG. 15

position it will be impossible to control the release of the locomotive brakes by the use of the automatic brake valve. In running position, Fig. 9, cavity *T* in the face of the rotary valve is not in communication with port *b* in the rotary-valve seat, so that air from the application cylinder of the distributing valve cannot pass through port *b*, cavity *T*, and port *k* to the atmosphere. Port *g* leading to the distributing-

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valve release pipe is connected by groove *h* in the face of the rotary valve with port *p* in the rotary-valve seat, which leads through the passage *p* in the casting to port *p* in the automatic brake valve, so that when the distributing valve is moved to release position by an increase in brake-pipe pressure, the air from the application cylinder and chamber will pass through the distributing-valve exhaust, distributing-valve release pipe, thence through port *g*, groove *h*, and port *p* in the independent brake valve to port *p* in the automatic brake valve, and out to the atmosphere, provided the automatic brake valve is also in running position. If the automatic brake valve is in running position and the locomotive brakes are being operated by the independent brake valve, they can be released by placing the independent brake valve in running position, as air from the application cylinder of the distributing valve can then pass out to the atmosphere through passage *p* in the casting and ports *p*, *q*, and *k* in the automatic brake valve.

21. Lap Position.—In lap position, which is shown in Fig. 15, all ports are blanked so that air cannot pass through the brake valve in any direction, except that port *o* still registers with port *t* to supply air to the space above the rotary valve. With the independent brake valve in lap position, the locomotive brakes can be applied by reducing brake-pipe pressure, but they cannot be released through the automatic brake valve.

22. Slow-Application Position. — Slow-application position, which is shown in Fig. 16, is to be used when it is desired to apply the locomotive brakes lightly or gradually independently of the train brakes, also when it is desired to prevent the locomotive brakes from being released by leaks from the application cylinder of the distributing valve, and thus prevent the locomotive from starting. When the handle of the valve is placed in slow-application position, the ports in the rotary valve and its seat are in the same relative position to each other as in lap position, except that port *o'* in the face of the rotary valve registers with port *b*

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in the rotary-valve seat. This allows main-reservoir air, reduced to a pressure of 45 pounds by the reducing valve, to pass from the reducing-valve pipe through port *t*, the groove extending from port *o*, Fig. 7, and the small passage in the rotary valve to port *o'* in the face of the rotary valve, thence through port *b* and the application-cylinder pipe into the application cylinder of the distributing valve, which operates

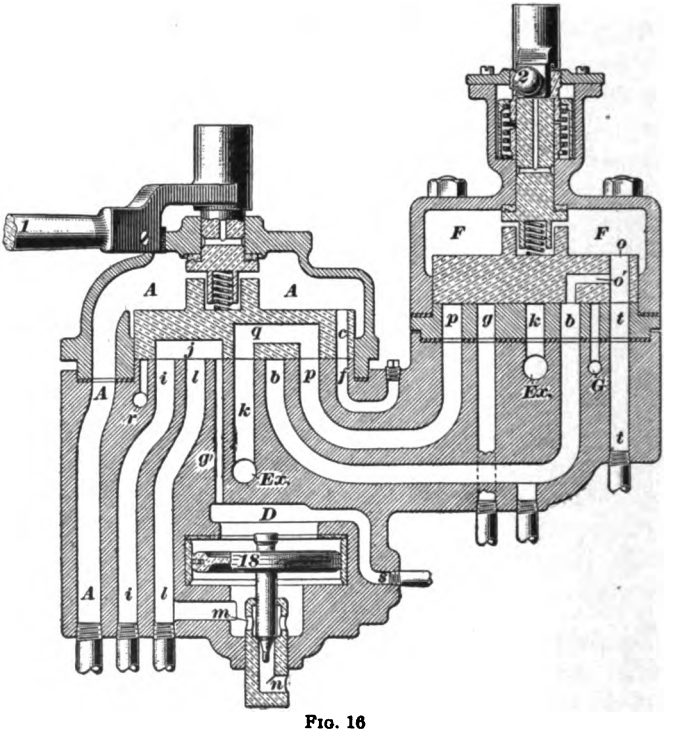

FIG. 16

the application piston and slowly applies the locomotive brakes. To graduate the application of the locomotive brakes, the handle is moved to slow-application position until the desired pressure is obtained in the application cylinder, when it is returned to lap position. The red hand on the small duplex gauge will register the brake-cylinder pressure of the application.

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When the locomotive is standing on a grade, the independent brake valve should be left in application position to keep the locomotive brakes applied.

23. Quick-Application Position.—Fig. 17 shows the valve in quick-application position. This position is to be used when it is desired to make a quick application of the independent brake. The handle of the independent brake

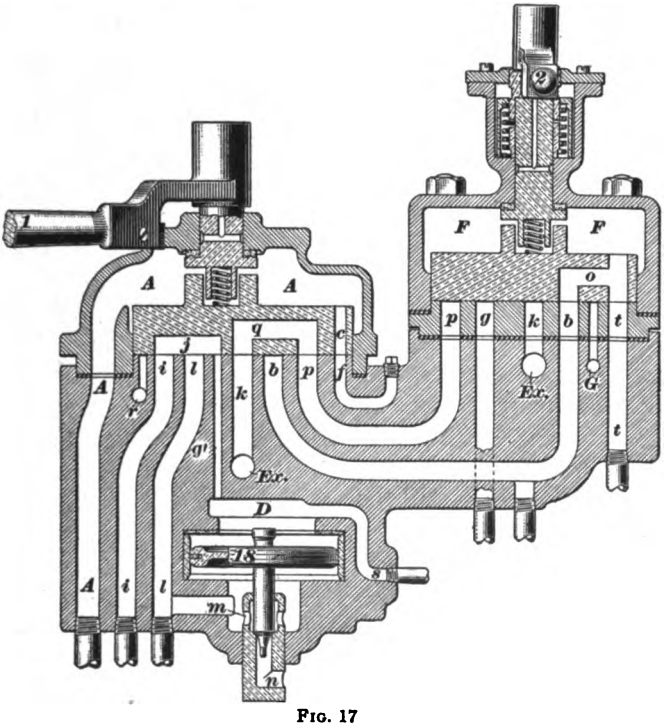

FIG. 17

valve should be moved to quick-application position and held there until the locomotive brake is fully applied. If the handle is not held in quick-application position, the return spring will move it back to slow-application position. When the handle is in quick-application position, the groove extending from port *o* in the rotary valve, Fig. 7, and the groove extending from port *t* in the rotary-valve seat, Fig. 6, forms a

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direct connection between ports *t* and *b*, and there is a much larger opening between them than in the slow-application position, so that air flows rapidly from the reducing-valve pipe through port *t*, the groove extending from port *o*, and port *b* to the application cylinder of the distributing valve.

RELATION OF INDEPENDENT BRAKE VALVE TO AUTOMATIC BRAKE VALVE

24. From the description of the operation and passage of air through the independent brake valve in the various positions of its handle, it will be seen: (1) that with the rotary valve of the independent brake valve in release position the locomotive brakes will be released independently of the train brakes and regardless of the position of the automatic brake valve; (2) that placing the independent brake valve in running position gives the control of the exhaust of the distributing valve to the automatic brake valve, so that the automatic brake valve can be used to release the locomotive brakes through the independent brake valve by moving the automatic brake valve to running position when the independent brake valve is in running position; (3) that when the independent brake valve is in lap position, the locomotive brakes cannot be released; (4) that slow-application position will slowly or gradually apply the locomotive brakes independently of the train brakes and without regard to the position of the automatic brake valve; and (5) that quick-application position will also apply the locomotive brakes independently of the train brakes and without regard to the position of the automatic brake valve, and that it will apply the brakes much quicker than the slow-application position.

The application and release positions of the independent brake valve operate the application piston in the distributing valve to apply and release the locomotive brakes independently of the automatic brake valve or of any variations of brake-pipe pressure.

The independent brake valve, except when held in release position, will not interfere with the automatic application of

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the locomotive brakes, but will block their release unless it is in release or running position.

If the independent brake valve is held in quick-application position, air will flow to the application cylinder of the distributing valve the full volume of port *t*, and if the reducing valve is adjusted too high or if it leaks badly, the pressure in the locomotive brake cylinders will be raised above the standard; but if it is not held in quick-application position, the return spring will return it to slow-application position and air will feed into the application cylinder only in the small volume that passes through port *o'* in the rotary valve. In such a case, the safety valve can discharge the air from the application cylinder faster than it can pass through port *o'*, and in this way will prevent too high a pressure in the brake cylinders.

The independent brake valve should be used preferably for applying and releasing the locomotive brakes when the train brakes are not to be operated at the same time.

RETURN-SPRING ARRANGEMENT

25. The **return-spring arrangement** of the independent brake valve is intended to make it impossible for the motorman to leave the brake-valve handle either in release

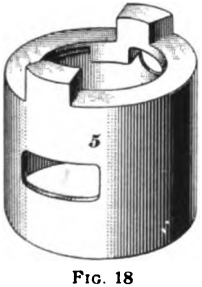

FIG. 18

FIG. 19

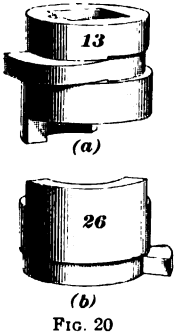

FIG. 20

position or in quick-application position. It consists of a *return spring casing 5*, Fig. 18, a *return spring 6*, Fig. 19, an *upper clutch 13*, Fig. 20 (*a*), and a *lower clutch 26*, Fig. 20 (*b*),

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all of which, when assembled, fit in the return-spring chamber in the body of the brake valve. This chamber is shown in Fig. 21, which is a sectional view of the brake-valve body with the return-spring arrangement removed. In this view is shown the *return-spring casing screw 8*, the *return spring stop 27*, the *oil plug 20*, and the *oil passage a*.

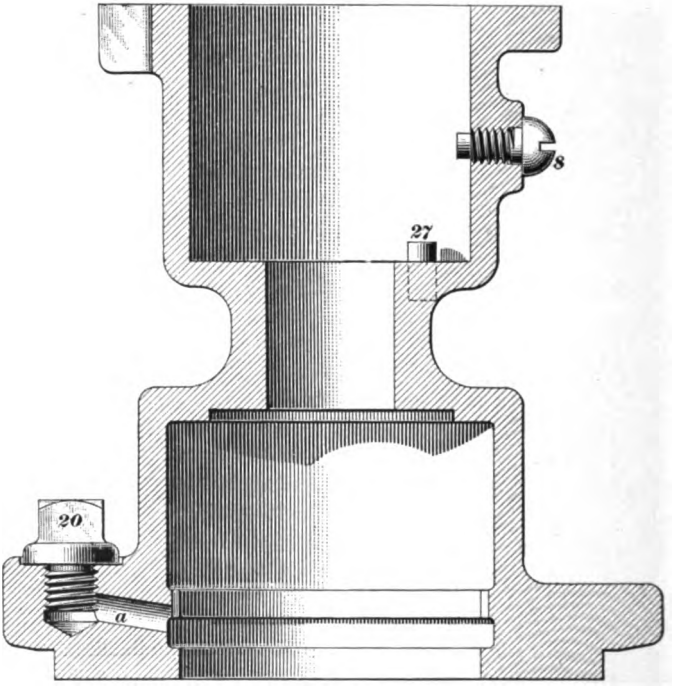

FIG. 21

Moving the valve handle from running position to release position puts the return spring under tension, so that the spring will return the handle to running position if the handle is let go. The spring exerts no influence on the brake-valve handle between running and slow-application positions. Moving the handle from slow- to quick-application position again puts the spring under tension that returns the handle to slow-application position if the handle is let go. The

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brake valve, therefore, will not stay in either release or quick-application position unless held there.

26. Action of the Mechanism. — The return-spring mechanism is operated through the medium of the rotary-key stem and the brake-valve handle. The lower clutch *26*, it will be observed, has a lug on its lower end that by resting against the return-spring stop *27*, Fig. 21, prevents this clutch from being turned to the left in the spring chamber. Its upper end is notched out to fit a similar notch in the bottom end of the upper clutch *13*. These notches are such that the brake-valve handle can turn the upper clutch from slow-application position to release position without disturbing the lower clutch. In moving the handle to the right, however, the two clutches engage in slow-application position, so that moving the handle beyond that position toward quick-application position causes the upper clutch to rotate the lower clutch to the right. As the casing *5* holds the upper end of the spring *6* stationary, this places the spring under tension and furnishes the power to move the handle back to slow-application position.

The lower end of the return spring rests against the far side of the lug of the lower clutch, which holds it stationary; the upper end of the spring rests against the stop-lug of the casing. In the running position of the brake valve, the lug on the upper clutch strikes against the lug on the casing, and moving the handle to release position causes the casing to be rotated to the left. As the lower end of the spring is held stationary by the lower clutch, turning the casing to the left puts the spring under tension and furnishes the power to return the handle to running position. It will thus be seen that the upper clutch is a device for moving the casing when the handle is turned to the extreme left and for moving the lower clutch when the handle is moved to the extreme right.

27. Removing the Return-Spring Arrangement. To remove the return-spring arrangement, first move the rotary-valve handle to release position and while holding it there remove the casing screw *8*, Fig. 21. Move the handle

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back to running position, take off the rotary-valve handle, take out the three cover screws, and remove the cover. Place the thumb over one of the casing lugs and hold the casing down while prying up the upper clutch *13* by inserting a pointed tool under the lug that engages the lug of the casing. This will disengage the upper clutch from the lower one and release the tension of the return spring *6*, as will be indicated by a slight click. The upper clutch, casing, spring, and lower clutch can then be removed in the order stated.

28. Replacing the Return-Spring Arrangement. In order to replace the return-spring arrangement easily, the rotary-valve key and stem should be in position in the valve body and the casing screw *8* removed. Place the lower clutch *26* on the rotary-key stem with the lug down, drop it into the return-spring chamber, and turn it until the lug is against the return-spring stop *27* and to the right of it, the front of the brake valve facing the person doing the work. Next, drop the spring *6* over the key stem and lower clutch and bring the end of the spring against the right face of the lug of the lower clutch. Next, drop the casing *5* over the spring and bring the return-spring stop-lug up against the top end of the spring. Turn the rotary-valve key until the position pin (located near the top of the key stem) points toward the casing screw hole. Place the upper clutch *13* properly on the key stem with the flat end up, and press the clutch down as far as it will go. This brings the clutch lug between the lugs of the casing. Next, place the brake-valve handle on the key stem and move it to release position. This will put tension on the spring and will bring the screw slot opposite the casing screw. Press the casing down until its lugs are flush with the top of the valve body, and then screw the casing screw all the way in; it will extend into the slot in the casing as intended. Let the brake valve return to running position and press the upper clutch down as far as it will go; this will cause it to take its proper position with respect to the lower clutch, the two clutches fitting together. Next, remove the handle, secure the cover in place, and replace the handle.

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NO. 14 DISTRIBUTING VALVE

29. General Remarks.—The No. 14 distributing valve with its double-chamber reservoir is the most essential part of the E L equipment and operates the locomotive brakes only. It takes the place and performs all the functions of the triple valves, auxiliary reservoirs, double-check valves, and high-speed reducing valves used with the former type of locomotive brake equipments. It is directly connected to the double-chamber reservoir, and all the pipe connections, of which there are five, are made to the reservoir.

30. Description.—Figs. 22, 23, and 24 are perspective views of the distributing valve and its double-chamber reservoir. Figs. 22 and 23 show the distributing valve connected to its double-chamber reservoir. Fig. 22 is a view of the application-cylinder-cap side of the distributing valve and shows three of the pipe connections to the reservoir. Fig. 23 is a view of the equalizing-cylinder-cap side of the distributing valve, showing two of the pipe connections to the reservoir. Fig. 24 shows the distributing valve separated from its double-chamber reservoir. From these views it will be seen that all pipe connections, five in number, are made to the double-chamber reservoir, and that the distributing valve can be separated from its double-chamber reservoir without disturbing any of the pipe connections.

Fig. 25 is a side view of the double-chamber reservoir sectioned in such a manner as to show the partition between the pressure chamber and the application chamber, as well as the relative sizes of these chambers. Also, it shows the ports *MR*, *BP*, and *o*, as well as the core and the drain plugs. The reservoir is divided into two chambers, namely the *Pressure Chamber* and the *Application Chamber*. The pressure chamber represents an auxiliary reservoir, and the application chamber combined with the application cylinder represents a brake cylinder. They have the relative proportions to each other of an auxiliary reservoir and its proper brake cylinder with 8-inch piston travel, so that when the pressure chamber is

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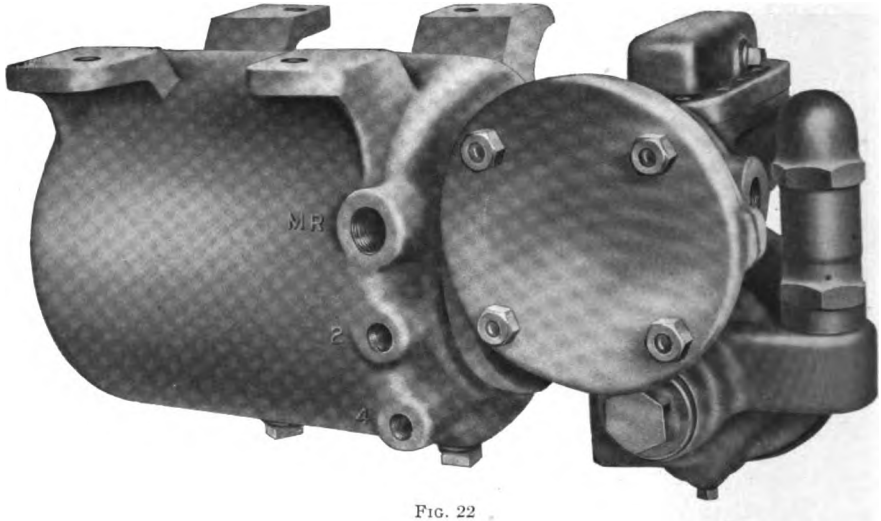

FIG. 22

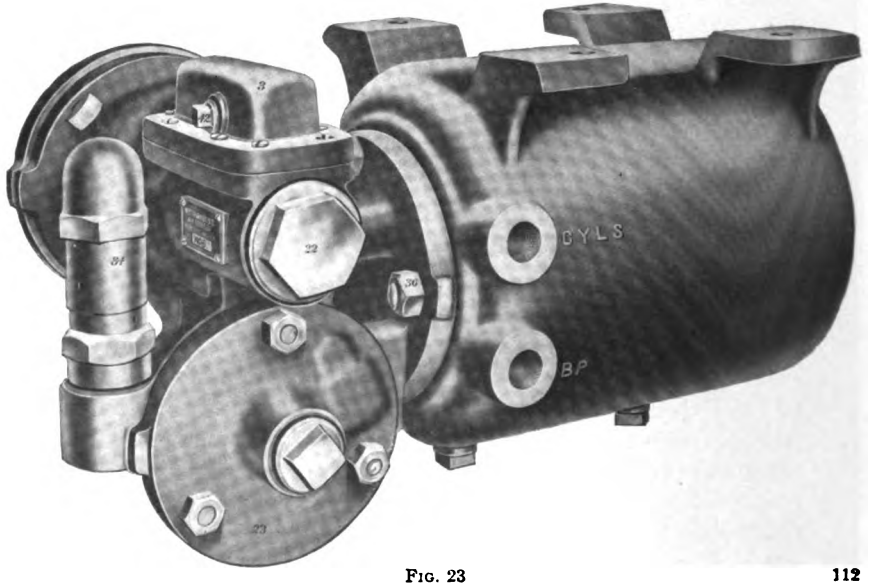

FIG. 23

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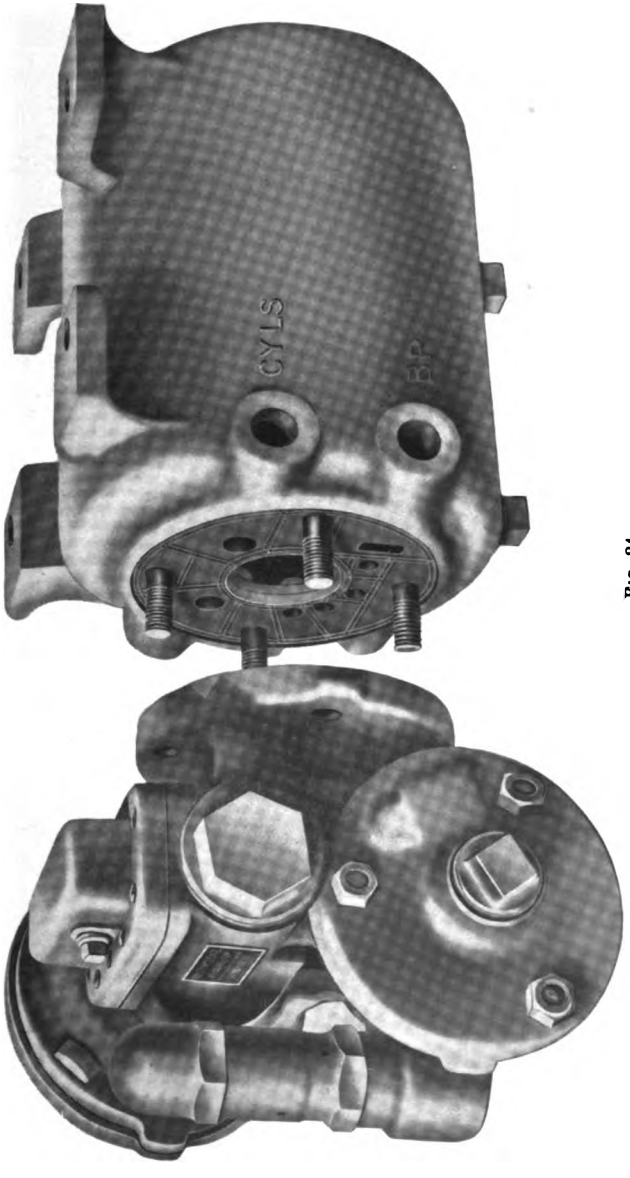

Fig 24

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charged with air at 70 pounds per square inch, the same as that in the brake pipe and the auxiliaries on the train, the volume of air therein will equalize in both chambers at 50 pounds, and in that proportion at every other auxiliary-reservoir pressure. The volume of the application-cylinder pipe is at all times included in the volume of the application cylinder, and the volume of the application cylinder of the distributing valve is included in the volume of the application chamber at all times, except when the equalizing slide valve is in emergency position, at which time the equalizing valve closes communication between the application cylinder and the application chamber. The volume of the equalizing-valve chamber in the distributing valve is included in the volume of the pressure chamber in all positions of the distributing valve.

31. Fig. 26 is a plan view of the distributing-valve face of the double-chamber reservoir, showing the pipe connections to the double-chamber reservoir as well as the ports in the distributing-valve face of the reservoir.

Fig. 27 is a view of the distributing valve removed from its reservoir.

Fig. 28 is a plan view of the reservoir face of the distributing valve, showing the ports in the reservoir face of the valve.

Fig. 29 is a sectional view of the distributing valve, showing passage *m* and the ports *u* and *Cyls.* connecting with this passage, a portion of the application-valve cover and equalizing-cylinder cap being broken away to show how port *MR* connects with the application-valve chamber *A* and the entrance of port *BP* into the equalizing-cylinder cap. Also, it shows the ports *2*, *4*, *o*, and *w*.

Fig. 30 (*a*) is a view of the face of the graduating valve, showing its cavities *t* and *y*; (*b*) is a view of the top of the equalizing valve with the sides broken away so as to show the graduating-valve seat and the ports *s*, *r*, *z*, *k*, and *f*, which pass entirely through the equalizing valve.

Fig. 31 (*a*) is a view of the equalizing valve, showing the ports *s*, *r*, *z*, *k*, and *f*, which pass entirely through the valve,

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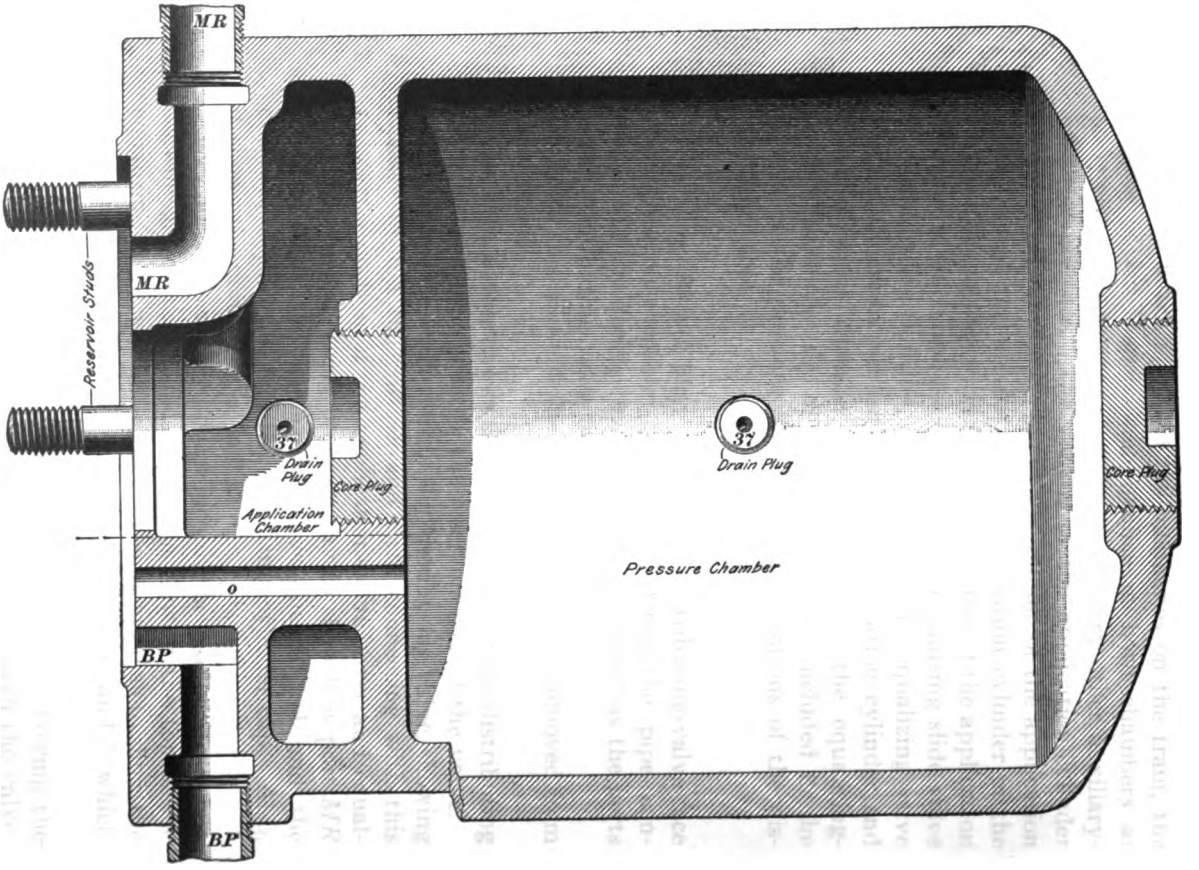

FIG. 25

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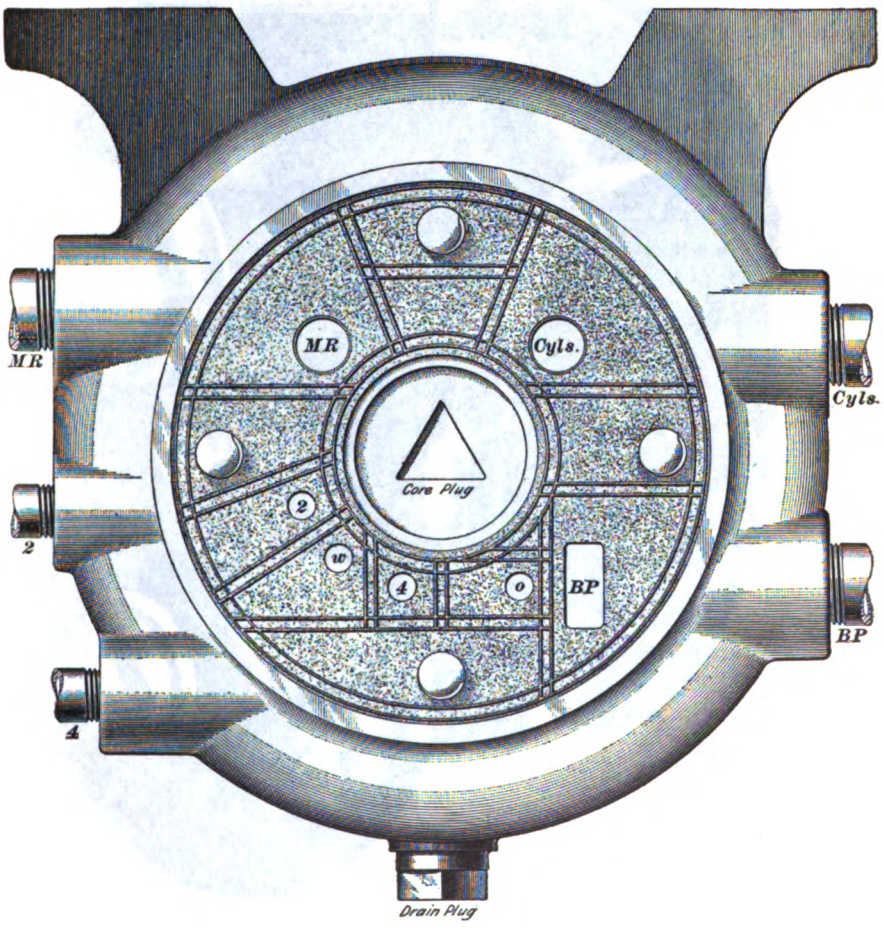

FIG. 26

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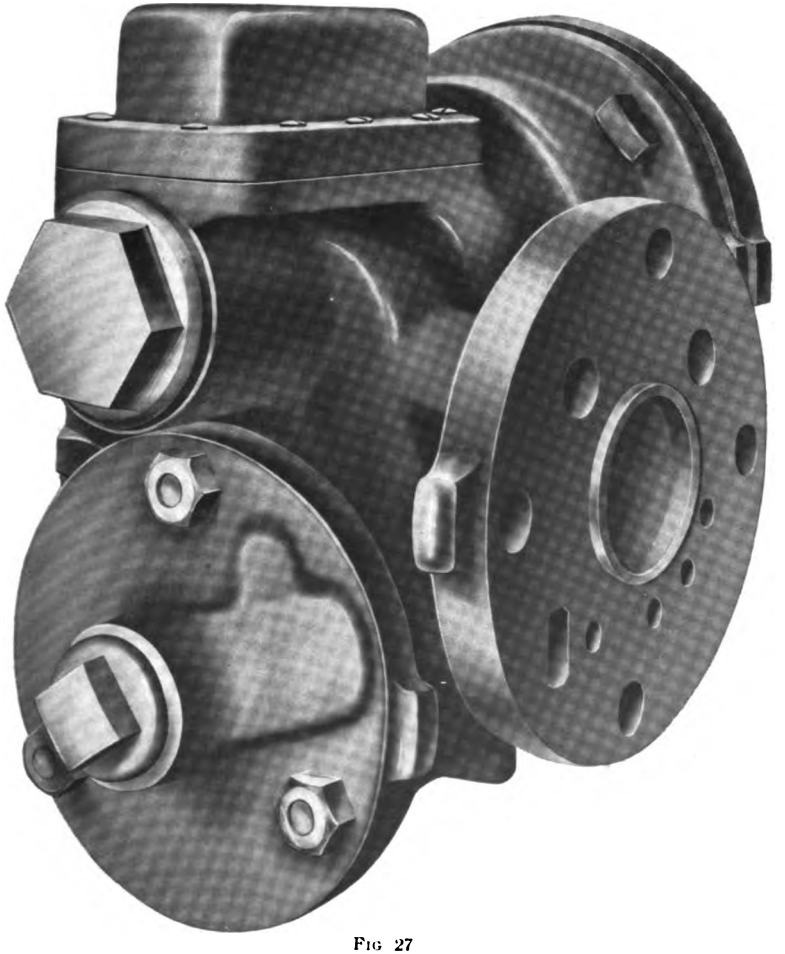

FIG 27

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and the cavities *k*, *n*, *q*, *r*, and *s* in the face of the valve. The equalizing valve is represented as transparent in order to show the form of the ports *s*, *r*, *z*, *k*, and *f*, as well as the small port leading from cavity *q* to cavity *r*; (*b*) is a view of the equalizing valve seat, showing the seven ports, *f*, *h*, *h'*, *h''*, *i*, *l*, and *w*, in the valve seat.

Fig. 32 (*a*) is a view of the exhaust-valve seat, showing the exhaust ports *d* and *e*, which lead to the brake-cylinder exhaust port of the distributing valve; view (*b*) is a perspective view of the exhaust valve *16* and its spring *17*, the side of the valve being broken away so as to show the port that extends through the valve; (*c*) is a view of the face of the application valve *5*, showing the port *a*, which extends through the valve, and the round opening into which the application-valve pin *18* fits; (*d*) is a view of the application-valve pin *18*. This pin is of steel and fits snugly in the opening *18* in the application-piston stem. It extends upwards into the large round opening in the face of the application valve *5*, and its function is to transmit the motion of the application piston *10* to the application valve *5*. The pin *18* is grooved to receive the pin *ab*, view (*e*), in the application piston and a similar pin that projects into the large round opening in the application valve *5* (indicated in view (*c*) by the small arch on the upper face of the valve) so that the application valve cannot be put in wrong end to; (*e*) is a view of the application piston *10*. This piston controls the movement of the application valve *5* and the exhaust valve *16*. It is moved back and forth by creating a difference of pressure on its two faces. Its stem is broken away so as to show the rivets *a* that secure the exhaust-valve yoke *1* to the stem; also, the stem is broken away to show the pin *a b* that fits in the groove in the application-valve pin *18*. The guide, or solid piston, *47* on the stem just back of piston *10* makes a snug fit in the cylinder between the application-piston cylinder and the exhaust-valve bushing, so that it is nearly air-tight. It acts as a dashpot to make piston *10* move back and forth gradually and thus steadies the movement of the valves *5* and *16*;

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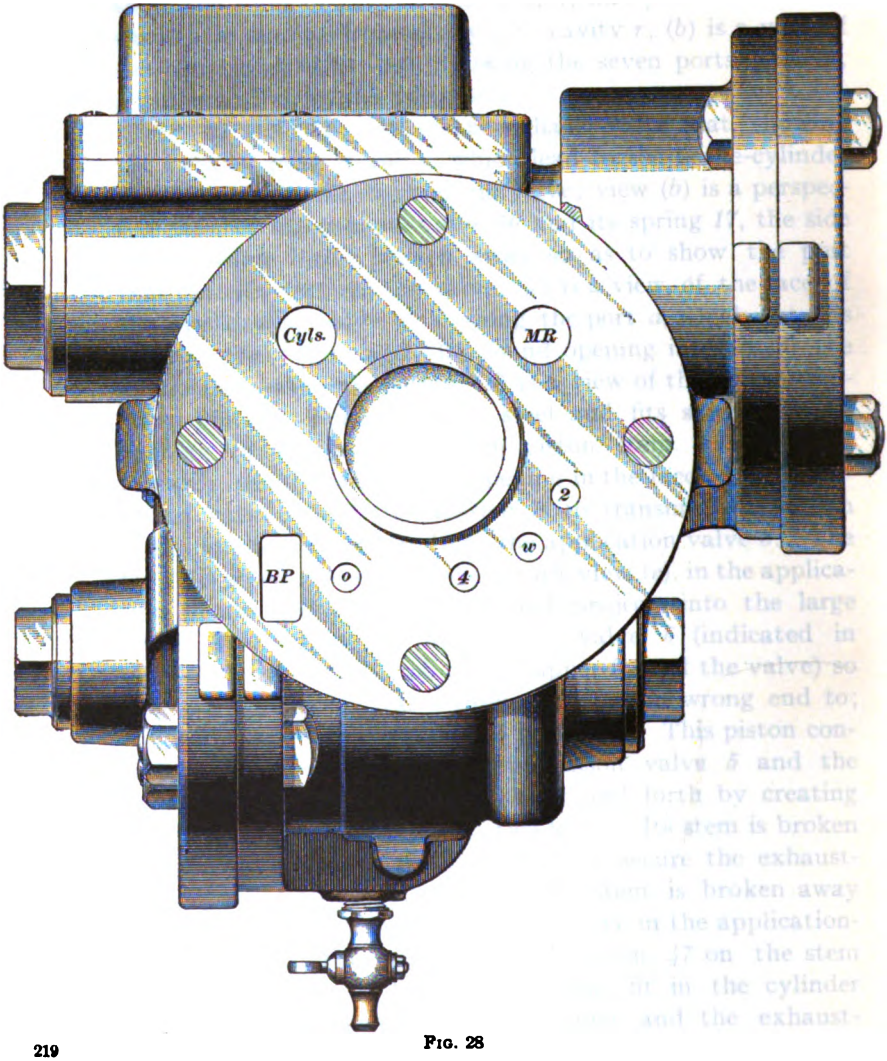

FIG. 28

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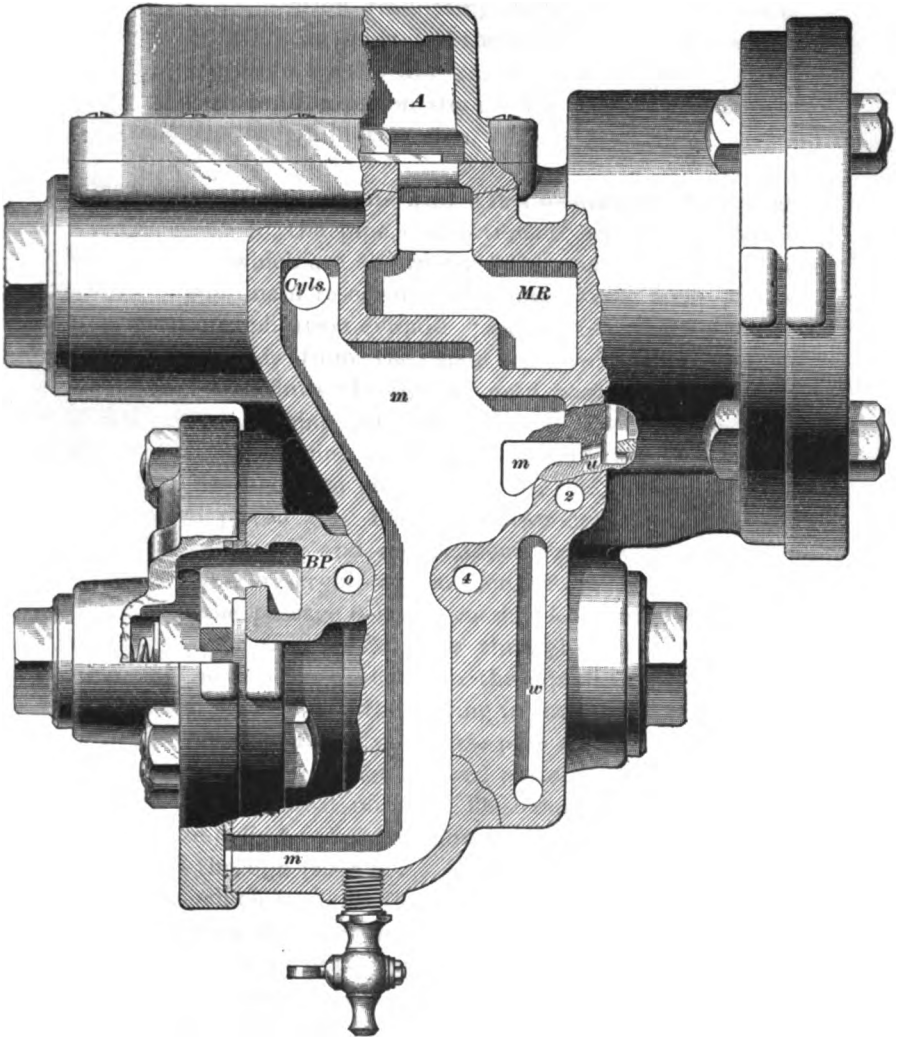

FIG. 29 § 64

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(*f*) is a view of the application graduating stem *19*; (*g*) is a view of the application graduating spring *20*; and (*h*) is a view of the application graduating-stem nut *21*. The stem *19* and spring *20* fit in the end of the application-piston stem, and are held there by the nut *21*, which is screwed on the end of the application-piston stem. The nut *21* also serves as a guide for the graduating stem *19*.

32. Pipe Connections and Air Passages.—Referring to Figs. 22 to 33, the pipe connections to the double-chamber reservoir, which are shown by letters and figures, are as follows: *MR*, main reservoir; *BP*, brake pipe; *Cyls.*, brake cylinders; *2*, application-cylinder pipe; *4*, distributing-valve release pipe. Air from the main reservoir pipe entering connection *MR* flows through a cored passage around the exhaust-valve bushing into chamber *A*, Figs. 29 and 33. Air from the brake pipe entering the connection *BP*, passes through a passage into chamber *p*, Fig. 33, on the brake-pipe side of piston *26*. The application-cylinder pipe connects the automatic and independent brake valves to the double-chamber reservoir at the connection *2*. From this connection, the passage *h* in the casting leads into the application cylinder *G*, Fig. 33, also through port *h'* in the equalizing-valve seat, cavity *k* in the equalizing valve, and the port and passage *w* in the casting to the application chamber. The distributing-valve release-pipe connection is made at *4*. From this connection a cored passage leads to the distributing-valve exhaust port *i*. The connection *Cyls.* leads to the brake cylinder and is connected to the exhaust-valve chamber *B* through passage *c*. Passage *c* also connects with passage *m*, which leads to the lower part of the distributing valve. Passage *m* is used in connection with the quick-action cylinder cap to vent brake-pipe air into the locomotive-brake cylinders when an emergency application is made. Passage *m* also connects with port *u*, so that any water in chamber *B* can pass down to the lower part of the distributing valve and be drained off through the drain cock *38*. Passage *o* leads from the equalizing-valve chamber of the distributing

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valve into the pressure chamber. Port and passage *l* leads from the equalizing-valve seat to the safety valve *34*.

33. Port Connections in Equalizing Valve 31 and Seat.—Fig. 30 (*a*) and (*b*) shows the face of the graduating valve and the top of the equalizing valve, which forms the seat for the graduating valve. Fig. 31 (*a*) and (*b*) shows the face and seat of the equalizing valve. When the equalizing valve is in release position, cavity *k* in the face of the valve forms a connection between the ports *h'*, *i*, and *w* in the seat, which opens communication between the application cylinder *G*, the application chamber, and the distributing-valve release pipe, Fig. 33. Also, in release position, cavity *s* in the equalizing valve connects port *h''* with port *l* in the valve seat, so that if the brake is applied by the independent brake valve, the application-cylinder pressure will not exceed the amount for which the safety valve is adjusted.

When the equalizing valve is moved to service position, Fig. 34, cavity *k* no longer connects ports *h'* and *w* with port *i*, but port *z* in the equalizing valve registers with port *h'* in the seat, which allows air to pass from the pressure chamber

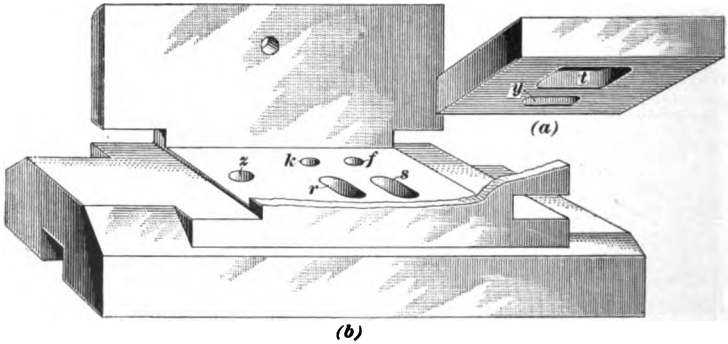

FIG. 30

and equalizing-valve chamber into the application cylinder through passage *h*. Cavity *n* in the equalizing valve connects ports *h* and *w* in the valve seat so that the air entering passage *h* from port *h'* is also free to enter the application chamber. Port and cavity *r* in the equalizing valve register

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with port h'' in its seat, port and cavity s register with port l, and cavity t in the graduating valve connects port r with port s, which allows air entering the application cylinder G to pass to the safety valve. Cavity y in the graduating valve also connects ports f and k in the top of the equalizing valve, and port f in the equalizing valve registers with port f in the equalizing-valve seat. This allows brake-pipe air to pass from port f in the equalizing-valve seat through port f in the equalizing valve to cavity y in the graduating valve, thence through port k to cavity k in the equalizing valve and out through port i into the distributing-valve release pipe. There are two reasons for passing brake-pipe air into the distributing-

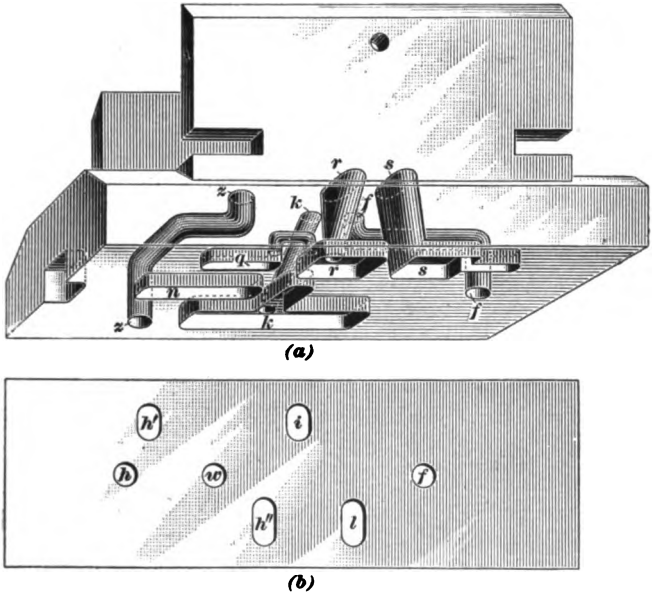

FIG. 31

valve release pipe during an automatic service application. First, to assist in reducing brake-pipe pressure and thus furnish a quick-service feature similar to that of the types K and L triple valves; secondly, to partly fill the distributing-valve release pipe and thus prevent a drop in application-cylinder pressure when the equalizing valve is moved to

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release position and it is desired to hold the locomotive brakes applied while the train brakes are being released. As the distributing-valve release pipe extends from the distributing valve to the brake valves at each end of the locomotive, considerable air is required to fill the pipe; hence, if the pipe were not partly filled with air when the equalizing valve moved to release position, air from the application cylinder and chamber would expand into the empty release pipe. This would result in a very low, or ineffective, brake-cylinder pressure when it was desired to hold the locomotive brakes applied while releasing the train brakes.

34. When the equalizing valve is in service-lap position (see Fig. 35) the same port connections are made in the valve and its seat as in service position, but cavity *t* in the graduating valve does not connect ports *r* and *s*. This prevents the flow of air from the application cylinder to the safety valve; likewise cavity *y* in the graduating valve is moved from over port *f* in the equalizing valve and thus prevents brake-pipe air from passing into the distributing-valve release pipe; also the graduating valve closes port *z* in the top of the equalizing valve and cuts off the flow of air from the equalizing-valve chamber to passage *h*.

When the equalizing valve is moved to emergency position, Fig. 36, the end of the valve uncovers port *h'* in its seat so that air from the pressure chamber can pass directly into the application cylinder. Cavity *n* in the equalizing valve no longer connects ports *h* and *w*, consequently the application chamber is cut off from the application cylinder, and as the volume of the application cylinder is very small, the pressure in the pressure chamber and the application cylinder equalizes quicker and at a much higher pressure than in service applications. Also, in emergency position, cavity *q* registers with port *h''*, and cavity *r* registers with port *l*. Cavity *q* is connected with cavity *r* through a small port, shown in Fig. 31 (*a*), which is of such a size as will permit air to pass from the application cylinder to the safety valve just a trifle faster than it can enter the application cylinder through port *u*

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in the rotary valve of the automatic brake valve. In emergency-lap position the port connections in the equalizing valve and its seat are the same as in emergency position, since the equalizing piston is held out at the end of its cylinder by the greater pressure in the pressure chamber.

DUTY OF PARTS OF DISTRIBUTING VALVE

35. The duty of the equalizing piston *26* is to control the movement of the equalizing valve *31* and the graduating valve *28*; also to open and close the feed-groove *v*. It is caused to move by creating a difference of pressure on its two faces, the greater pressure moving it toward the lesser pressure. The equalizing valve *31* opens and closes communication between the pressure chamber, application cylinder, and application chamber, also between the application cylinder, application chamber, and distributing-valve exhaust. The equalizing valve is made shorter than the distance between the shoulders on the equalizing piston stem, so that when the equalizing valve is in service position, piston *26* can move the graduating valve far enough to open and close port *z* without moving the equalizing valve. The graduating valve *28* opens and closes port *z* in the equalizing valve *31* and thus graduates the flow of air from the pressure chamber into the application cylinder, and its cavity *y* opens and closes the communication between ports *k* and *f* in the top of the equalizing valve, when a graduated-service application is made with the automatic brake valve. The graduating valve also opens communication between the application cylinder and the safety valve, through ports *r* and *s* in the top of the equalizing valve, in service position, and closes this communication when in service lap position.

36. The application piston *10* controls the movement of the application valve *5* and the exhaust valve *16*. It is caused to move by increasing or decreasing the pressure in chamber *G* above or below that in chamber *B*. The application valve *5* controls or graduates the flow of main-reservoir air from chamber *A* to the exhaust-valve chamber *B* and the

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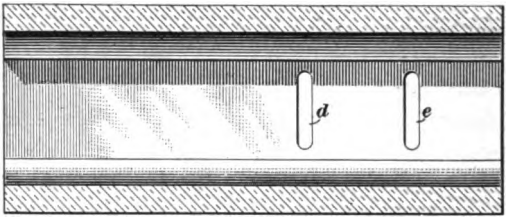
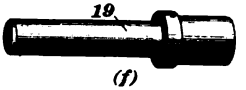


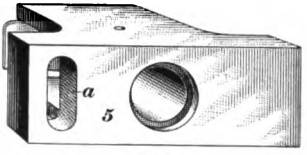
(a)

(b)



(f)

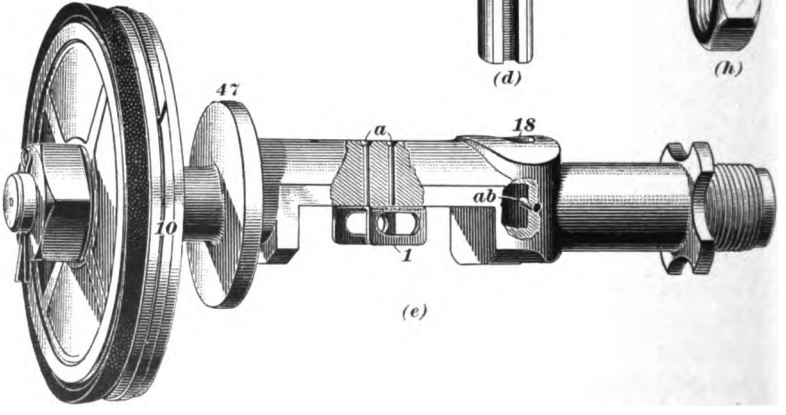
(g)



(c)

(d)

(h)



(e)

FIG. 32

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locomotive brake cylinders when the brakes are being applied by either the automatic or the independent brake valve. The exhaust valve *16* opens and closes the brake cylinder exhaust ports *e* and *d*. It is made shorter than the distance between the shoulders on the application-piston stem, so that, when the exhaust valve is in lap position, piston *10* can move valve *5* far enough to open and close the port in the application-valve seat without disturbing the exhaust valve. The application-piston guide *47* is made nearly an air-tight fit in its bushing, so that, in addition to acting as a guide for piston *10*, it also acts as a dashpot that assists in steadying the movement of the application piston and its slide valves *5* and *16*. The application-piston graduating stem *19* and spring *20* act as a cushion for piston *10* when it is moved to application position. They also assist the pressure in chamber *B* in moving the application piston *10* back to lap position when the pressures in chamber *B* and in the application cylinder *G* are nearly equalized. The graduating stem *19* and its spring *20* are held in the stem of piston *10* by the nut *21*. The stem *19* touches the cap nut just as the piston *10* starts from lap to application position, so that as piston *10* moves to application position, the spring *20* is compressed and when the pressure in chamber *B* becomes a trifle greater than that in chamber *G*, the spring *20* will assist in moving piston *10* back to lap position. The equalizing piston graduating sleeve and spring in the plain cylinder cap, and the valve stem *50* and spring *55* in the quick-action cylinder cap, perform the same functions as the graduating stem and spring in a triple valve. They assist in preventing the equalizing piston from moving past service position during a service application on a short train, and also aid in starting the equalizing piston from emergency position.

The application piston *10* is provided with a packing leather and packing-leather expander as well as a brass packing ring, in order to prevent air leaking from chamber *G* into chamber *B* during an application of the brakes.

The function of the application-valve pin *18* is to move the application valve *5* when piston *10* moves. The pin fits

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snugly in the stem of piston *10* and in valve *5* with the result that piston *10* cannot move without moving valve *5*. If at any time it should become necessary to remove piston *10* from its cylinder, the application valve *5* and pin *18* must first be taken out.

37. There are two pistons in the distributing valve. The upper piston, called the *application piston*, controls the movement of the supply and exhaust valves that supply air to the brake cylinders during an application, and exhausts brake-cylinder air to the atmosphere during a release of the locomotive brakes; the lower piston, called the *equalizing piston*, controls the movement of the equalizing and graduating valves. The equalizing piston and the equalizing and graduating valves, which operate the same as the triple piston, slide valve, and graduating valve in a triple valve, control the flow of air from the pressure chamber into the application cylinder and chamber during an automatic application of the brake, and from the application chamber to the distributing valve exhaust when the brake is to be released by the automatic brake valve. Also, the equalizing and graduating valves control the flow of air from the brake pipe into the distributing-valve release pipe during an automatic-service application. Variations in brake-pipe pressure operate the equalizing piston and its slide valves the same as the triple piston, slide, and graduating valves in a triple valve. The application piston is operated by changes of pressure in the application cylinder. With the ordinary automatic brake the pressure in the brake cylinder depends on the amount of air the triple valve passes from the auxiliary reservoir into the brake cylinder, but with the E L equipment the supply of air for the brake cylinders comes from the main reservoir direct, and the pressure in the brake cylinders is determined by the pressure in the application cylinder of the distributing valve. With an automatic application the pressure in the application cylinder depends on how much air the equalizing piston and its slide valves pass from the pressure chamber into the application cylinder.

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38. There is another method of varying the pressure in the application chamber to apply and release the locomotive brakes, which does not require any movement of the equalizing piston and its valves. This is done by means of the independent brake valve, which can be operated to pass main-reservoir air directly into the application cylinder or discharge the air from the application cylinder to the atmosphere, thus operating the application piston independently of the variation in brake-pipe pressure. The independent brake valve does not pass main-reservoir air direct to the brake cylinder like the straight-air brake valve. It passes main-reservoir air, at a reduced pressure of 45 pounds, into the application cylinder of the distributing valve; also, it exhausts the air from this cylinder, which causes the application piston to be moved, and this operates the application and exhaust valves to apply or release the locomotive brakes. As the supply of air for the brake cylinders is taken from the main reservoir direct, and the operation of the application piston depends on the pressure in the application cylinder *G*, it follows that, so long as the pressure in the application cylinder is maintained, the same pressure will be maintained in the brake cylinders, regardless of brake-cylinder leakage and variations in brake-piston travel.

AUTOMATIC OPERATION OF DISTRIBUTING VALVE

39. Figs. 33 to 40, inclusive, show conventional views of the distributing valve and its double-chamber reservoir. As the parts, ports, and cavities in the distributing valve are located so that they cannot be shown in a true sectional view, these conventional views have been prepared to help in the study of the operation of the valve. The views show the pressure chamber and application chamber of the double-chamber reservoir as a part of the distributing valve and of a different shape from the original, being smaller in proportion to the size of the valve, but with the same relative proportion to each other. However, it must be borne in mind that these conventional views are given in order to simplify

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the tracing of the air through the various ports, as well as to help explain the operation of the valve, rather than to show its actual construction and the proper location of the various ports.

40. Automatic Charging Position.—When the distributing valve is charging, air from the main reservoir enters at the connection *MR*, Fig. 33, and passes through the passage *a* into the application-valve chamber *A*. This supply of main-reservoir air is always present around the application valve *5*, unless the main-reservoir cut-out cocks or the distributing-valve cut-out cock is closed.

When air is first admitted to the brake pipe, it enters the distributing valve at the brake-pipe connection and passes into chamber *p*. If the equalizing piston *26* is not already in release position, the air entering chamber *p* will force it to release position; then all parts will assume the positions shown in Fig. 33. The feed-groove *v* is opened by the piston *26*, and the air from chamber *p* will pass through it into the equalizing-valve chamber, thence through port *o* to the pressure chamber, until full brake-pipe pressure is obtained in this chamber. The feed-groove *v* is made of such a size that it will charge the pressure chamber at the same rate as the feed-groove in a triple valve will charge its auxiliary reservoir.

41. Automatic Service Position.—Fig. 34 shows the distributing valve in automatic service position. When making an automatic service application of the brakes, brake-pipe pressure is reduced. This reduces the pressure in chamber *p* of the distributing valve, and since the feed-groove *v* is very small, the pressure in chamber *p* can reduce faster than the air can pass back through the feed-groove. The greater pressure in the equalizing-valve chamber will then move the equalizing piston *26* to the right. This movement cuts off communication between the equalizing-valve chamber and chamber *p* by closing the feed-groove *v*. The graduating valve *28*, which fits snugly between the shoulders on the piston stem, is also moved on the back of the equalizing valve

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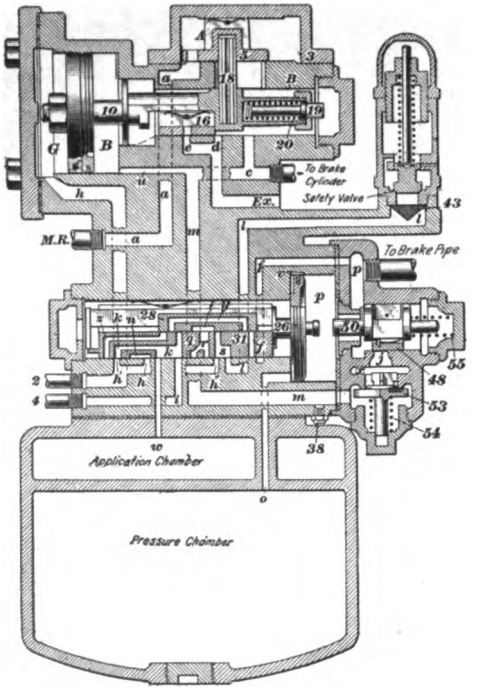

FIG. 33

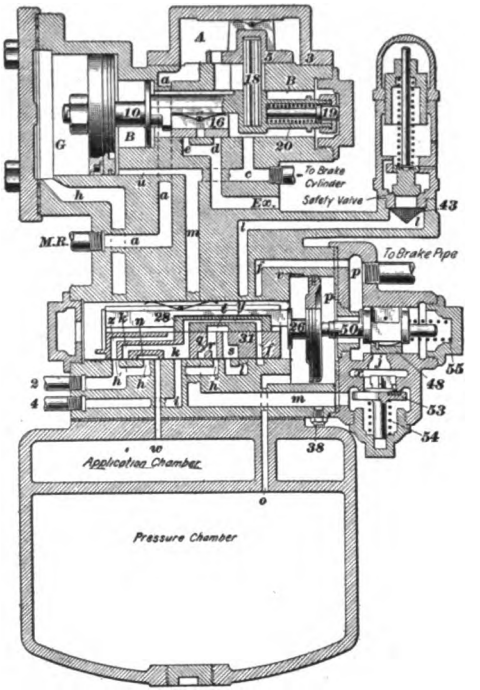

FIG. 34

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so as to uncover the upper end of port *z* in the equalizing valve, and cavity *t* in the graduating valve *28* connects the ports *r* and *s* in the top of the equalizing valve. By this time, the shoulder on the end of the piston stem has engaged the equalizing valve and a further movement of piston *26* carries the equalizing valve with it and all these parts will assume service position as shown. When the valves are in this position, cavity *k* in the face of the equalizing valve is moved from over ports *h'* and *w*, so that these ports are no longer connected with the exhaust port *i*. Cavity *n* in the face of the equalizing valve connects ports *h* and *w* in the valve seat, which opens communication between the application cylinder and the application chamber. Also port *r* is moved over port *h''*, and port *s* over port *l*. As ports *r* and *s* are connected through cavity *t* in the graduating valve, this opens communication between the application cylinder, application chamber, and safety valve. Piston *26* moves to the right until it strikes the valve stem *50*, when port *f* in the equalizing valve registers with port *f* in the valve seat. This allows air from the brake pipe to pass through port *f* in the equalizing valve seat and port *f* in the equalizing valve to cavity *y* in the graduating valve, thence through port *k* and cavity *k* in the equalizing valve and port *i* in its seat to the distributing-valve release pipe. Air from the brake pipe passing into the release pipe assists in reducing brake-pipe pressure and partly fills the distributing-valve release pipe, reasons for which were explained in Art. **33.** Port *z* in the equalizing valve registers with port *h'* in the valve seat. This allows air from the equalizing-valve chamber and the pressure chamber to flow through ports *z* and *h'* into passage *h*, thence to the application cylinder, also through port *h*, cavity *n*, and port *w* into the application chamber. The equalizing piston stands against the valve stem *50*, but does not compress the graduating spring *55*, because of its resistance and the fact that the slightly greater pressure in the equalizing-valve chamber is gradually reduced by the air passing through ports *z* and *h'* to the application cylinder *G*. If the pressure in the equalizing-valve chamber should be

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greatly in excess of the pressure in chamber *p*, the graduating spring would be compressed and the parts would assume emergency position.

Air passing from the pressure chamber into the application cylinder *G* builds up a pressure on the left side of the application piston *10* that forces this piston to the right. This movement of piston *10* also moves the application valve *5* and exhaust valve *16* over to the right to the position shown in Fig. 34. The graduating stem *19* strikes the cap nut and the graduating spring *20* is compressed. The exhaust valve *16* first closes the exhaust ports *e* and *d* and thus cuts off the brake cylinders from the exhaust port and the atmosphere. Application valve *5* then connects chamber *A* with the port in the application-valve seat and thus allows main-reservoir air to flow from chamber *A* through the port in the application-valve seat into the exhaust-valve chamber *B*, thence through port *c* to the brake cylinders.

42. Automatic Service Lap Position.—If the reduction in the brake-pipe pressure is not great enough to equalize the pressures in the application cylinder, application chamber, and the pressure chamber, air from the equalizing-valve chamber will continue to flow through ports *z* and *h'* until the pressure on the pressure-chamber side of the equalizing piston *26* is a trifle less than that remaining in chamber *p* and in the brake pipe. The greater pressure in chamber *p* will then move the equalizing piston *26* and graduating valve *28* to the left, until the graduating valve closes the upper end of the port *z*, as shown in Fig. 35, stopping the flow of air from the pressure chamber to the application chamber and cylinder *G*, thus preventing any further increase in application-cylinder pressure. Cavity *y* in the graduating valve is moved away from port *f* in the top of the equalizing valve, thus cutting off the flow of air from the brake pipe to the distributing-valve release pipe. The graduating valve has also closed the top end of port *s* and cut off communication between the application cylinder and the safety valve, so that if the safety valve leaks, it cannot reduce the pres-

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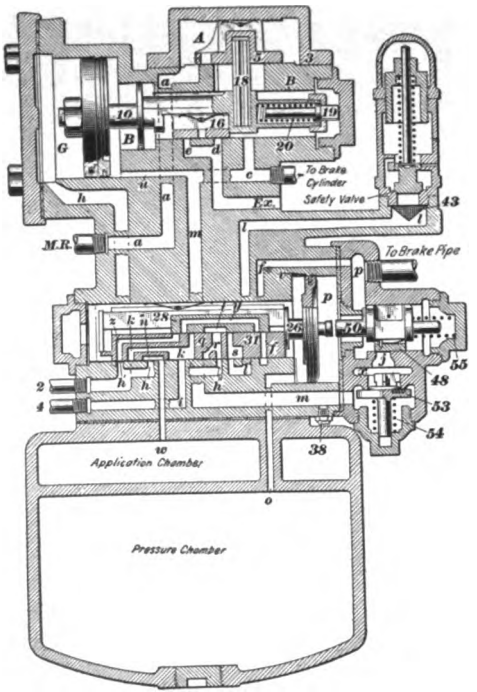

FIG. 35

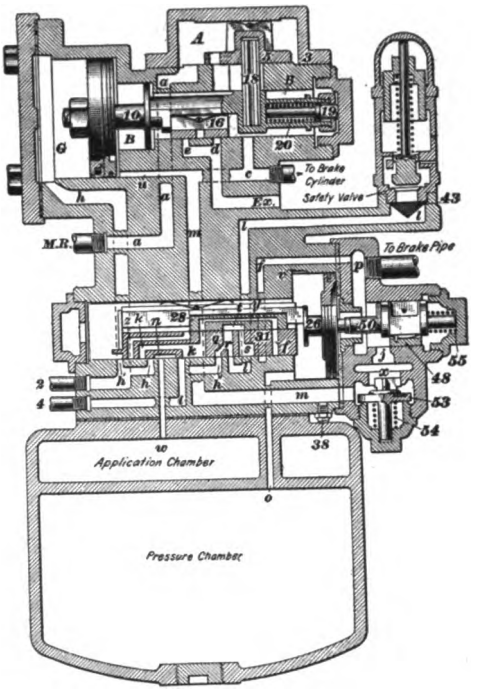

FIG. 36

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sure in the application cylinder. Air from the application-valve chamber *A* will continue to flow to the exhaust-valve chamber *B* and out through port *c* to the locomotive brake cylinder until the pressure in chamber *B* slightly exceeds that in the application cylinder *G*, when the greater pressure in the exhaust-valve chamber, assisted by the graduating spring *20* and stem *19*, will move piston *10* to the left far enough to close the port in the application-valve seat and stop the flow of air from chamber *A* to the exhaust-valve chamber *B*. This is called *automatic service lap position*.

43. Second Reduction.—If another reduction in brake-pipe pressure is now made, the greater pressure in the equalizing-valve chamber will again move the equalizing piston *26* to the right until it strikes the valve stem *50*, as in Fig. 34. Since the equalizing valve *31* is already in service position, this movement of piston *26* moves only the graduating valve, which opens the top end of port *z* and connects the top end of ports *f* and *k* through cavity *y*, and ports *r* and *s* through cavity *t*. Air from the pressure chamber will again pass through ports *z* and *h'* to passage *h*, thereby increasing the pressure on the application-cylinder side of the application piston *10* above that in the exhaust-valve chamber, which will move piston *10* and valve *5* to the right and open the port in the application-valve seat. Main-reservoir air will then flow from chamber *A* to the exhaust-valve chamber *B*, thence through port *c* to the locomotive brake cylinders. When the pressure in the equalizing-valve chamber becomes a trifle less than the pressure in chamber *p*, equalizing piston *26* will again be forced to the left by the greater pressure in chamber *p* and the graduating valve *28* will close the top end of ports *z*, *f*, and *s*. When the pressure in the exhaust-valve chamber *B* becomes slightly higher than that in the application cylinder *G*, the greater pressure in chamber *B* and the force of the application graduating spring *20* will move the application piston *10* to the left, taking the application valve *5* with it, thereby closing the port in the application-valve seat.

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As already mentioned, piston *26*, with its valves *28* and *31*, graduate the flow of air from the pressure chamber to the application cylinder the same as a triple valve graduates the flow of air from the auxiliary reservoir to the brake cylinder; hence, a given reduction in brake-pipe pressure will cause the distributing valve to pass enough air into the application cylinder to give a pressure therein equal to that in a brake cylinder of 8-inch piston travel, consequently, the locomotive brakes will be applied with the same brake-cylinder pressures as the car brakes.

Each reduction applies the locomotive brakes harder as long as the pressure in the pressure chamber exceeds that in the application cylinder, but when these have equalized the brake is fully set and a further reduction would be only a waste of brake-pipe air. When a brake-pipe pressure of 70 pounds is carried, a 20-pound gradual brake-pipe reduction will cause the pressures in the application chamber, application cylinder, and pressure chamber to equalize at 50 pounds pressure, resulting in a 50-pound brake-cylinder pressure, the same as a car brake that has standard piston travel. When the equalizing valve and the graduating valves are in service position, the application cylinder is in communication with the safety valve through ports *h''* and *r*, cavity *t*, port *s*, and port and passage *l*. The safety valve, being set at 68 pounds, will limit the pressure in the application cylinder (the latter being governed by the former) to that amount.

44. Automatic Release Position.—Fig. 33 shows the distributing valve in release position. To release the locomotive brakes through the automatic brake valve, it is necessary that both the automatic and independent brake valves be in running position. When the automatic brake valve is placed in release position, air from the main reservoir passing into the brake pipe increases the brake-pipe pressure, which causes the triple valves on the cars to move to release position and release the train brakes. At the same time, the increase of brake-pipe pressure also increases the pressure in chamber *p* of the distributing valve above that in

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the equalizing-valve chamber, which forces the equalizing piston *26* to the left, carrying with it equalizing valve *31* and graduating valve *28*, to release position. When in this position, the equalizing piston *26* opens the feed-groove *v*, which allows air from chamber *p* to flow through groove *v* past piston *26* to the equalizing-valve chamber, and out through port and passage *o* into the pressure chamber, until the pressure equalizes on both sides of the equalizing piston *26*. The graduating valve *28* has the top end of ports *z*, *f*, and *s* blanked. Cavity *k* in the equalizing valve connects ports *h'* and *w* with the exhaust port *i*, which leads to the distributing-valve release pipe, but as the automatic brake valve is in release position, its rotary valve closes the opening from the release pipe to the atmosphere and prevents the distributing valve from releasing the locomotive brakes. In order to connect the distributing-valve release pipe with the atmosphere and thus release the locomotive brakes with the automatic brake valve, the automatic brake valve must be moved to running position. This allows the air from the application cylinder *G* and the application chamber to escape to the atmosphere through ports *h'* and *w*, cavity *k*, and port *i* into the distributing-valve release pipe, thence through the independent brake valve and out to the atmosphere through the automatic brake valve. As the air in the application cylinder *G* reduces, the greater pressure in the exhaust-valve chamber *B* moves piston *10* to the left, carrying with it application valve *5* and exhaust valve *16*. This movement of the application valve does not affect the port in the application-valve seat, but the movement of the exhaust valve *16* connects the brake cylinder with the atmosphere and allows the brake-cylinder pressure to escape through ports *d* and *e* and the brake-cylinder exhaust port *Ex*, thus releasing the locomotive brakes.

To graduate the release of the locomotive brakes, through the automatic brake valve, the handle should be left in running position just long enough to reduce the application-cylinder pressure the desired amount and then moved to lap, holding, or release position. As the pressure in the applica-

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tion cylinder reduces, the greater pressure in the exhaust-valve chamber will move piston *10* and valves *5* and *16* to the left; the exhaust valve *16* will allow brake-cylinder air to escape through ports *d* and *e* until the pressure in the exhaust-valve chamber is slightly less than that in the application cylinder, when the greater pressure in the application cylinder will move piston *10* and valve *16* to the right and stop the flow of brake-cylinder air to the atmosphere. The equalizing valve, being in release position, the application chamber and cylinder is connected to the safety valve through ports *h''*, *s*, and *l*.

45. Automatic Emergency Position.—When a sudden and heavy reduction in brake-pipe pressure is made, it causes the distributing valve to operate quick action, and the movable parts will assume the position shown in Fig. 36. This sudden and heavy reduction in brake-pipe pressure may be made by placing the automatic brake valve in emergency position, by the train parting, by a burst hose, or by opening a conductor's valve or an angle cock. The pressure in the brake pipe and chamber *p* of the distributing valve being suddenly reduced, the equalizing piston *26* moves quickly out to the full length of its cylinder. The knob on the piston stem strikes the valve stem *50* and moves it over against the tension of the graduating spring *55*. As the emergency valve *48* fits snugly between the shoulders on the valve stem *50*, it also moves to the right and uncovers port *j* in the valve seat. This allows brake-pipe air from chamber *p* to pass through port *j* to chamber *x*, which forces the check-valve *53* down against the resistance of the spring *54*. This allows brake-pipe air to flow to passage *m* in a large volume; it then passes through port *u*, Fig. 29, to chamber *B* back of the application piston *10*, and through port *c* into the brake cylinders. This makes a local reduction in brake-pipe pressure that insures the next distributing valve, or quick-action triple valve, going into quick action.

When the brake-cylinder and brake-pipe pressures have nearly equalized, the check-valve spring forces the valve *53*

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back to its seat, so that no air can pass from the locomotive brake cylinder into the brake pipe.

When piston *26* moves to the right it also carries the equalizing valve *31* with it to emergency position; port *h'* in the equalizing-valve seat is uncovered, and air from the equalizing-valve chamber passes through port *h'* to passage *h* and the application cylinder. Cavity *n* in the equalizing valve is also moved away from port *h*, thus closing communication between the application cylinder and the application chamber. Under these conditions the pressure chamber has only the small volume of the application cylinder to fill, consequently the pressure chamber and application cylinder will equalize quicker and at a much higher pressure than during a service application. The operation of the application piston *10*, application valve *5*, and exhaust valve *16* in emergency applications is the same as in service applications, except that they are moved to application position much quicker than in service applications. When the pressure in the exhaust-valve chamber *B* becomes equal to that in the application cylinder *G*, the application piston will be moved to *automatic emergency lap position*, Fig. 37. When the pressure chamber is charged to 70 pounds, an emergency application will equalize the pressures in the pressure chamber and application cylinder at about 65 pounds; but when the automatic brake valve is in emergency position, air from the main reservoir passes through a small port in the rotary valve and its seat into the application-cylinder pipe, thence to the application cylinder of the distributing valve, which raises the pressure therein above 65 pounds. The amount of pressure that will be allowed to accumulate in the application cylinder will be determined by the adjustment of the safety valve to which it is connected through port *h''* in the valve seat, cavity *q*, the small port leading from cavity *q* to port *r* in the valve, Fig. 31, and port *l* in the valve seat. Main-reservoir air can pass through the port in the rotary valve of the automatic brake valve in about the same volume that it can pass to the safety valve through the small port leading from cavity *q* to the port *r* in the equalizing valve, so that 68 pounds

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pressure will be held in the application cylinder, as this is the pressure for which the safety valve is set. Since the pressure in the brake cylinders is determined by the pressure in the application cylinder, 68 pounds will also be obtained in them. This high brake-cylinder pressure will cause a shorter stop to be made than with a service application.

46. In high-speed brake service, the operation of the distributing valve is exactly the same as in ordinary service, but with the high-speed brake service, the brake pipe being charged to 110 pounds pressure and the main-reservoir pressure being about 130 pounds, an emergency application will raise the pressure in the application cylinder, and consequently in the brake cylinders to about 93 pounds. In this case, however, the small port, connecting cavity *q* and port *r*, in the equalizing valve *31*, will allow air to pass from the application cylinder to the safety valve a little faster than it can enter the application cylinder through the automatic brake valve, so that the safety valve will reduce the pressure in the application cylinder from 93 to 75 pounds in about the same time as the high-speed reducing valve on the cars will reduce the brake-cylinder pressure to 60 pounds.

When the application-cylinder pressure is reduced to 75 pounds, a main-reservoir pressure of 130 pounds will force air into the application cylinder through the small port in the rotary valve of the automatic brake valve as fast as it can escape from the application cylinder through the small port leading from cavity *q* to port *r* in the equalizing valve, so that a pressure of 75 pounds will be maintained in the application cylinder and consequently in the locomotive brake cylinders. When the equalizing piston *26* and valves *28* and *31* are in emergency position, and the application piston and valves *5* and *16* have moved to service position and then lapped the ports in the application and exhaust-valve seats, the distributing valve is said to be in automatic emergency lap position.

47. If the emergency application is caused by a burst hose, by the opening of a conductor's valve, or by the train

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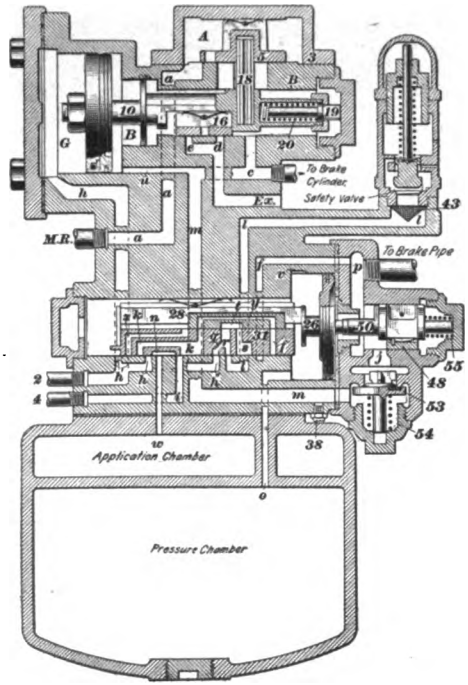

FIG. 37

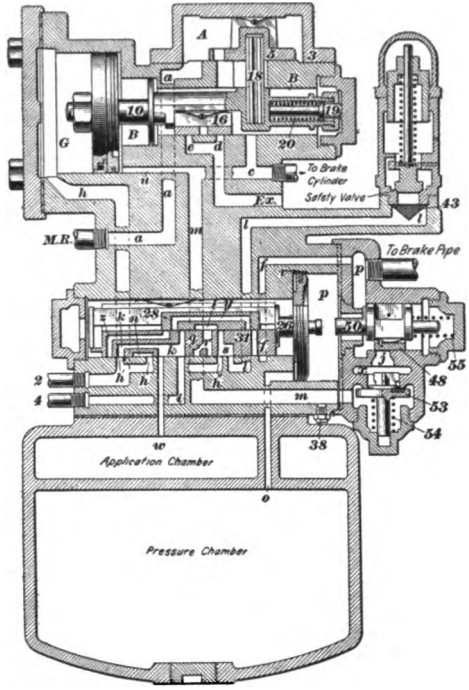

FIG. 38

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parting, the automatic brake valve must be lapped to save main-reservoir air. Under these conditions, the distributing valve will operate in the same manner as previously explained, but, since the automatic brake valve is not in emergency position, no main-reservoir air will pass to the distributing valve through the application-cylinder pipe, and therefore the brake-cylinder pressure will not be as high as if the application were made by the automatic brake valve. In high-speed service carrying 110 pounds brake-pipe pressure, the brake-cylinder pressure will be reduced to 68 pounds, this being governed by the safety valve. If only 70 pounds brake-pipe pressure is carried, the resulting brake-cylinder pressure will be but 50 pounds. After a full-service application, if a greater brake-cylinder pressure is necessary, main-reservoir pressure may be conveyed to the application cylinder of the distributing valve by placing the automatic brake valve in emergency position.

The automatic brake valve is operated in the same manner to release the brakes after an emergency application as after a service application, but the effect on the distributing valve is somewhat different. When the automatic brake valve is placed in release position, the brake-pipe pressure in chamber *p* of the distributing valve is increased above that in the equalizing-valve chamber and the equalizing piston and the valves *28* and *31* are moved to release position. As piston *26* moves back to release position, the graduating spring *55* forces the stem *50* and emergency valve *48* back to their normal positions. During this movement valve *48* closes port *j*. Cavity *k* in the equalizing valve *31* connects port *h'* with ports *w* and *i*, which allows the pressure in the application cylinder *G* to expand into the application chamber and the pressure will quickly equalize at 15 pounds. This will cause the application piston *10* to reduce automatically the brake-cylinder pressure to the same amount, which will be retained as long as the automatic brake valve is in release position. To release the brake fully, place the automatic brake valve in running position in order to connect the distributing-valve release pipe with the atmosphere.

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INDEPENDENT OPERATION OF THE DISTRIBUTING VALVE

48. Independent Application Position.—When the distributing valve is operated by means of the independent brake valve, piston *10* and valves *5* and *16* are the only parts that move. The equalizing piston *26* and its valves *28* and *31* are not influenced by the operation of the independent brake valve. When the independent brake valve is moved to either slow-application or quick-application position, air from the main reservoir, reduced to a pressure of 45 pounds by the C-6 reducing valve, passes through the independent brake valve and application-cylinder pipe directly to the application cylinder of the distributing valve. This movement of the rotary valve of the independent brake valve also closes communication between the distributing-valve release pipe and the atmosphere, so that air from the application cylinder and chamber cannot escape through the distributing-valve exhaust port *i*. The pressure in the application cylinder forces the application piston *10* to the right to the position shown in Fig. 38. The application valve *5* and the exhaust valve *16* will move with it, valve *16* will close the exhaust ports *d* and *e*, and valve *5* will then open the port in its seat that leads to chamber *B*. Main-reservoir pressure from chamber *A* will pass into the exhaust-valve chamber *B* and out to the brake cylinders through port *c* until the pressure in the exhaust-valve chamber is a trifle more than that in the application cylinder, when the greater pressure in the exhaust-valve chamber, assisted by the graduating spring *20*, will force piston *10* to the left until valve *5* closes the port in the application-valve seat. This position of the distributing valve is called *independent lap position*, Fig. 39.

A graduated independent application may be made by admitting a certain amount of pressure to chamber *G* in the distributing valve and then placing the independent brake valve in lap position, continuing this as often as desired until a full application is obtained. Each time the brake valve is lapped, the distributing valve will assume independent lap position. When a full independent application is obtained

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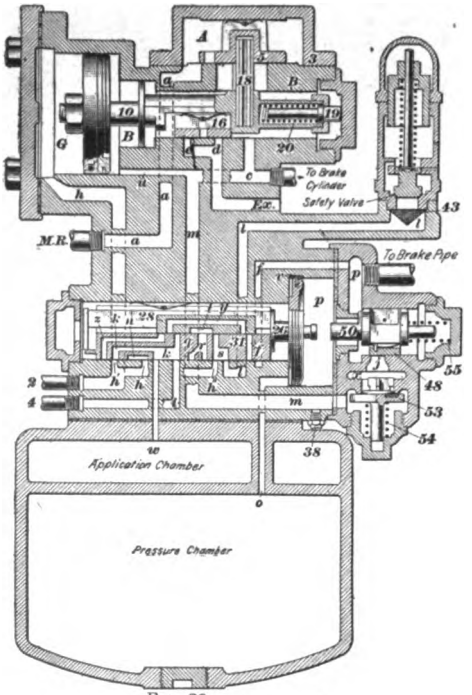

FIG. 39

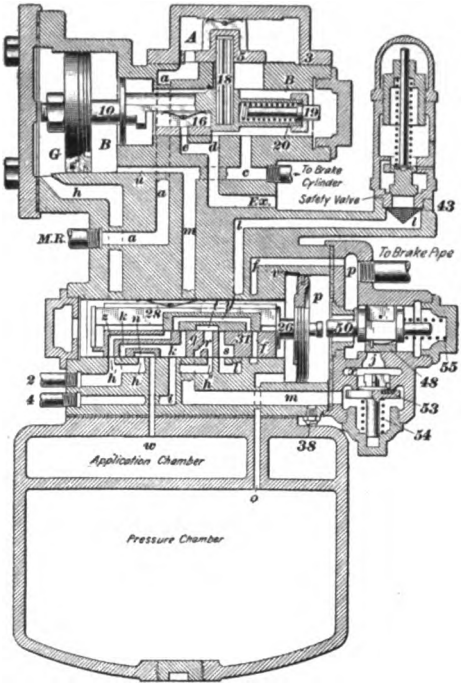

FIG. 40

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there will be a pressure of 45 pounds in the application cylinder and in the locomotive brake cylinders, this being the pressure for which the C-6 reducing valve is set. When the equalizing valve *31* and piston *26* are in release position, if the reducing valve is out of order or improperly adjusted, the safety valve will prevent the application-cylinder pressure from rising above 68 pounds, the pressure for which it is set, provided the independent brake valve is in slow-application position; but if the independent brake valve is in quick-application position, the larger ports in the brake valve will supply air to the application cylinder faster than it can escape through the safety valve, and the brake-cylinder pressure will be increased above the amount for which the safety valve is set.

49. Independent Release Position.—If the equalizing piston *26* is in release position when the locomotive brakes are being released by means of the independent brake valve, the movable parts of the distributing valve will assume the position shown in Fig. 33, which is exactly the same as when the brakes are released by the automatic brake valve. When the independent brake valve is moved to release position, it allows air to flow from the application chamber and cylinder *G* to the atmosphere. The greater pressure in the exhaust-valve chamber then moves piston *10* to the left, carrying valves *5* and *16* with it. Valve *16* opens port *d* and the port through valve *16* registers with port *e*. This allows air from the exhaust-valve chamber and brake cylinders to escape to the atmosphere through the brake-cylinder exhaust port *Ex*.

When the equalizing piston of the distributing valve is in release position and the automatic brake valve is in running position, the locomotive brakes can be released by placing the independent brake valve in running position. Under these circumstances, application-cylinder and chamber *G* air will flow through ports *h'* and *w*, cavity *k*, and port *i* into the distributing-valve release pipe, thence through the independent brake valve and out to the atmosphere through the automatic brake valve.

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The locomotive brakes may be released by the independent brake valve after they have been applied in service or emergency by the automatic brake valve, by moving the independent brake valve to release position. This allows the air in the application cylinder to escape through the application-cylinder pipe and the independent brake valve. However, if the automatic brake valve is in emergency position when releasing the locomotive brakes through the independent brake valve, it will be necessary to hold the independent brake valve in release position in order to prevent the brakes from reapplying, because, with the automatic brake valve in emergency position, main-reservoir air will be supplied to the application cylinder through the maintaining port *u* in the rotary valve of the automatic brake valve. Fig. 40 shows the position of the parts of the distributing valve after the brakes have been applied with an automatic service application and released in the manner just stated.

To graduate the release of the locomotive brakes through the independent brake valve, the handle of this valve should be moved to full-release position (or to running position, if the automatic brake valve also is in running position) long enough to reduce the pressure in the application cylinder the desired amount, and then moved to lap position. As the pressure in the application cylinder and chamber is reduced, the greater pressure in the exhaust-valve chamber will move the application piston *10* and exhaust valve *16* to the left, and reduce the brake-cylinder pressure a trifle below the application-cylinder pressure, when the application piston *10* and the exhaust valve *16* will move to the right and close ports *d* and *e* and retain the remaining pressure in the locomotive brake cylinders.

PRESSURE-MAINTAINING FEATURE OF DISTRIBUTING VALVE

50. The **pressure-maintaining feature** of the distributing valve is very valuable in connection with the E L equipment, for as long as there is air pressure in the application cylinder *G* of the distributing valve, the same

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amount of pressure will be maintained in the locomotive brake cylinders, regardless of the length of piston travel or the ordinary brake-cylinder leakage. This is due to the fact that the supply of air for the locomotive brake cylinders is taken from the main reservoir, and when the application piston *10* is in service-lap position, due to either an automatic or an independent application, a leak that reduces brake-cylinder pressure will also reduce the pressure in the exhaust-valve chamber of the distributing valve, which will cause the application piston *10* and valve *5* to be moved to the right by the greater pressure in the application cylinder *G*. The application valve *5* being moved to the right will open communication between chamber *A* and the brake cylinders through the port in the application-valve seat and allow main-reservoir air to pass to the locomotive brake cylinders until the pressure in the exhaust-valve chamber, and consequently in the brake cylinders, is equal to that in the application cylinder, when the application piston *10* will move valve *5* to the left far enough to close the port in the valve seat. This action of the distributing valve will be repeated each time the leaks reduce brake-cylinder pressure below that in the application cylinder. It is possible for the leaks from the brake cylinder to cause the application piston *10* and valve *5* to be moved to the right just far enough to supply main-reservoir air to the brake cylinders through the port in the application-valve seat as fast as it can escape through the leaks; then piston *10* would not move valve *5* back to lap position until the brakes were released through the brake valves.

If there are any leaks from the application cylinder of the distributing valve, this maintaining feature will be destroyed, because with the brakes applied and the brake valve in lap position, the leak will continue to reduce the pressure in the application cylinder. This will allow the greater pressure in the exhaust-valve chamber to move the application piston *10* and its valves to release position and exhaust brake-cylinder air. In such a case, however, it will be possible to hold the brake on by placing the independent brake valve in slow-application position.

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PLAIN AND QUICK-ACTION CYLINDER CAPS

51. Description. — Fig. 41 (*a*), (*b*), and (*c*) are views of the plain and quick-action cylinder caps; (*a*) is a view of the face of the plain cylinder cap removed from the distributing valve, showing the ports *BP* and *xb* in the face of the cap, also the face of the graduating sleeve *44* and the line *a b* on which the cap is sectioned for view (*b*). View (*b*) shows how the port *BP*, which is a continuation of the port *BP*, Figs. 28 and 29, divides, one branch leading to the equalizing-piston chamber and the other to the graduating-spring chamber; also, it shows how the port *xb* connects with the port *BP*. The port *xb* connects port *BP* with port *f* in the body of the distributing valve; (*c*) is a sectional view of the quick-action cylinder cap, which replaces the plain cylinder cap generally used with the No. 14 distributing valve. Without the quick-action cylinder cap, the operation of the equalizing portion of the distributing valve corresponds to the plain triple valve used with the old standard locomotive brake equipment; that is, no brake-pipe air is vented to the brake cylinders during an emergency application. When the quick-action cylinder cap is used, the distributing valve vents brake-pipe air into the locomotive brake cylinders, during an emergency application, thus corresponding to a quick-action triple. These quick-action cylinder caps are essential on helper locomotives, or on the second locomotive of a double-header. They are not furnished with the distributing valve by the manufacturers, unless specially ordered. The position assumed by the valves in the quick-action cylinder cap and the manner in which brake-pipe air is vented to the locomotive brake cylinders during an automatic emergency application is shown in Fig. 36. The valves in the quick-action cylinder cap do not operate during a service application, but when an automatic emergency application is made, they operate to vent some of the brake-pipe air to the locomotive brake cylinders. The brake-pipe air vented to the locomotive brake cylinders by the quick-action cylinder cap does not give any higher brake-cylinder

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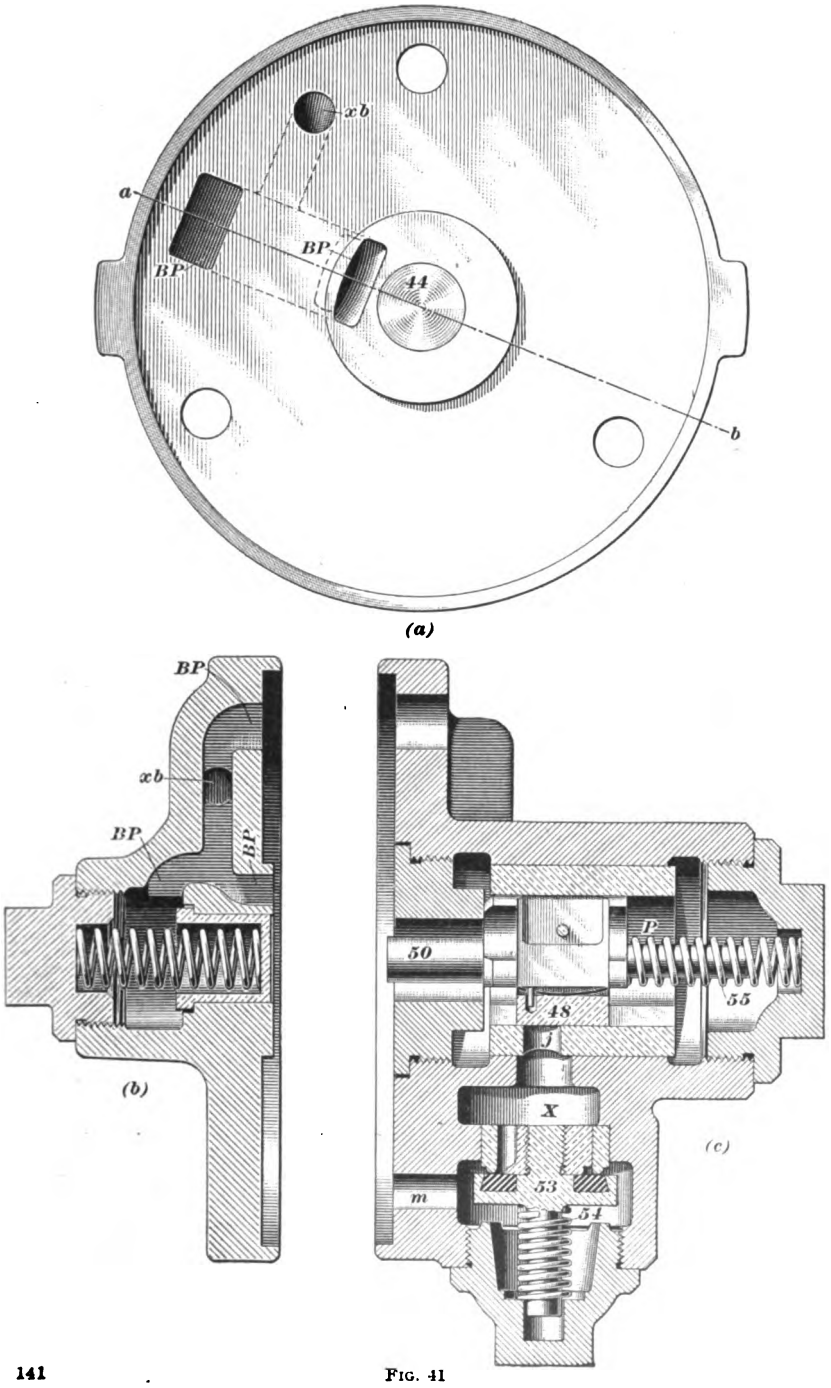

FIG. 41

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pressure, because the pressure obtained in the locomotive brake cylinders is always governed by the application-cylinder

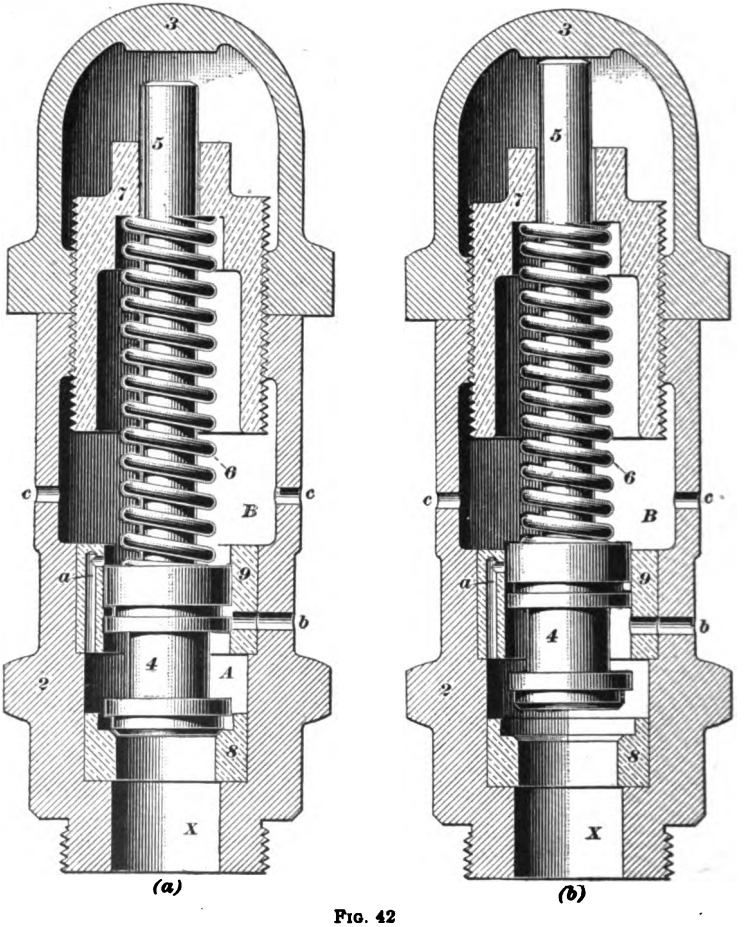

FIG. 42

pressure. But it causes a local reduction in brake-pipe pressure that insures the quick-action operation of the train brakes.

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TYPE E-6 SAFETY VALVE

52. General Remarks.—The E-6 safety valve is an essential part of the No. 14 distributing valve, as it takes the place of the high-speed reducing valves and the safety valves used with previous types of locomotive brake equipment. Its construction is such as to cause it to close quickly with a "pop" action, thus insuring its seating firmly, and to make it sensitive to slight differences of pressure.

53. Description.—In Fig. 42 is shown two views of the E-6 safety valve; view (*a*) shows the valve in its normal, or closed, position, and view (*b*) shows the valve in its open position. Referring to Fig. 42 (*a*) and (*b*), the names of the parts of the E-6 safety valve are as follows: *2*, valve body; *3*, cap nut; *4*, valve; *5*, valve stem; *6*, adjusting spring; *7*, adjusting nut; *8*, valve seat; *9*, bushing. The upward movement of stem *5* is restricted by striking the cap nut *3*. The cap nut *3* must be in place in order to have valve *4* open and shut properly. The bushing *9* acts as a guide for valve *4*. There are two vertical ports *a* that lead upwards through bushing *9* and out at the top of valve *4* into the spring chamber; and two ports *b* that lead through bushing *9* and the valve body *2* to the atmosphere, but only one of each of these ports is shown in Fig. 42. There are also two ports *c* that lead from chamber *B* through the valve body to the atmosphere. This safety valve is screwed into the opening that connects with port and passage *l* in the distributing valve.

54. Operation.— Air from passage *l* in the distributing valve enters the safety valve at *X*, Fig. 42 (*a*), and exerts an upward pressure on the under side of valve *4*. When the pressure under valve *4* slightly exceeds the pressure exerted by the adjusting spring *6*, valve *4* is raised, and, as the valve rises from its seat, a larger area is exposed to the air pressure, so that its upward movement is very quick. As valve *4* moves up it closes the top end of the two ports *a*, thus closing communication between chambers *A* and *B*, and at the same time it uncovers the two ports *b*, which opens communication

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between chamber *A* and the atmosphere. This allows air that flows past valve *4* into chamber *A* to escape to the atmosphere through the two ports *b*. When the pressure below valve *4* decreases, the spring *6* gradually moves valve *4* down, which in turn gradually closes the two ports *b*, thus restricting the flow of air to the atmosphere, until the top end of valve *4* uncovers the two ports *a*. Air from chamber *A* then passes through the two ports *a* to chamber *B* in a larger volume than can escape through the ports *c*. This builds up a pressure in chamber *B*, above valve *4*, that helps the spring *6* to seat valve *4* quickly and thus cut off the flow of air to the atmosphere.

This safety valve, when used with the No. 14 distributing valve, should be set at 68 pounds.

B-6 FEED-VALVE

DESCRIPTION

55. The **B-6 feed-valve,** used with the No. 14 E L equipment, is an improved form of the slide-valve feed-valve type. It differs from the previous types of slide-valve feed-valve in that it will charge to the regulated pressures somewhat quicker and will maintain the pressure more accurately under the variable conditions of short and long trains. It is connected to a pipe bracket located in the piping between the main reservoir and the K-14 brake valve, Fig. 1, and is supplied with air from the main reservoir. It regulates the pressure in the feed-valve pipe, also in the brake pipe in running and holding positions of the K-14 automatic brake valve. It has a double-regulation feature, so that it can be quickly adjusted to change the regulated pressure from one standard pressure to another.

56. Three views of the B-6 feed-valve are shown in Fig. 43. View (*a*) shows the feed-valve attached to the pipe bracket, and views (*b*) and (*c*), the valve removed from its

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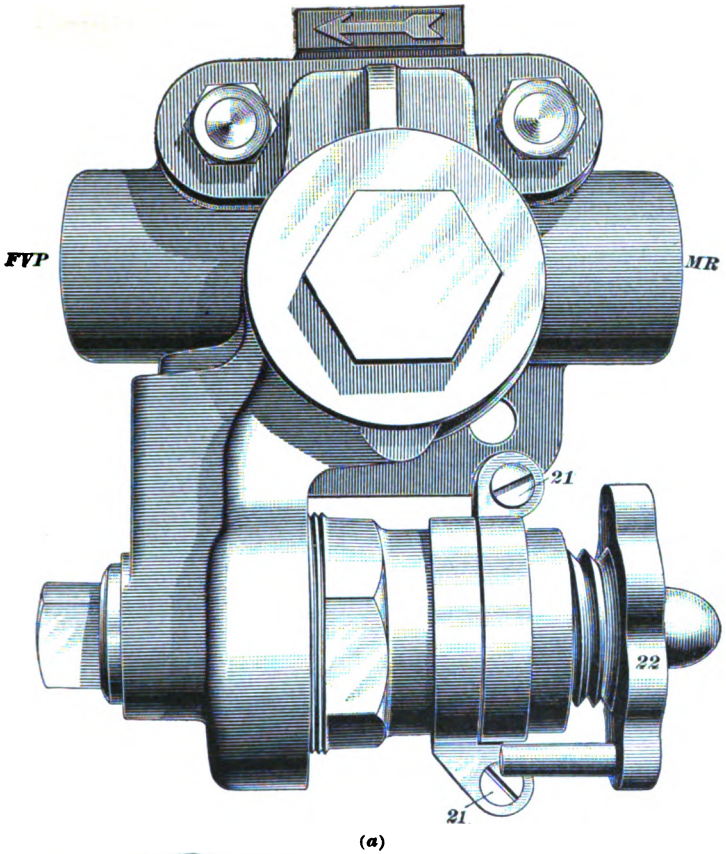
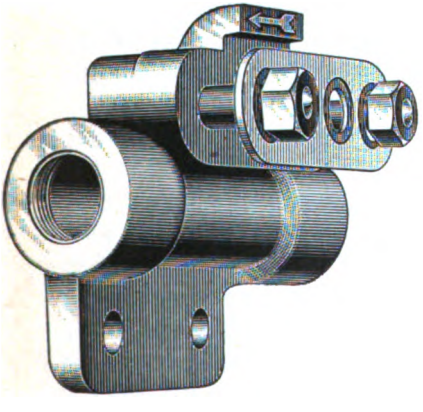


(a)



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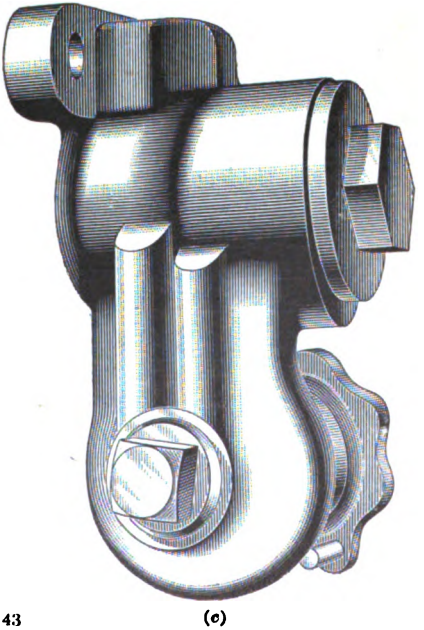

(c)

FIG. 43

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pipe bracket. The pipe bracket (type F, crossed passage) is standard for the E L equipment, and has the passages crossed. The main-reservoir connection *MR* leads to the left port, and the feed-valve pipe connection *FVP* leads to the right port in the bracket.

57. Figs. 44 and 45 are conventional views, showing the ports, passages, and movable parts of the feed-valve on one plane. These views are given to help explain the operation of the feed-valve and not to represent its actual construction. Fig. 44 shows the valve in its open position, and Fig. 45 shows the valve in its closed position.

The numbers and names of the parts are as follows: *2*, valve body; *3*, pipe bracket; *5*, cap nut; *6*, piston spring; *7*, piston-spring tip; *8*, supply-valve piston; *9*, supply valve; *10*, supply-valve spring; *11*, regulating-valve cap; *12*, regulating valve; *13*, regulating-valve spring; *14*, diaphragm; *15*, diaphragm ring; *16*, diaphragm spindle; *17*, regulating spring; *18*, spring box; *19*, upper stop; *20*, lower stop; *21*, stop-screws; and *22*, adjusting handle.

58. The supply-valve piston *8* has neither packing rings nor grooves, but is made solid with a smooth surface next to the wall of the cylinder, in which it moves. It is necessarily made a loose fit in its cylinder so that a small volume of air can pass from chamber *B* into chamber *G*. The supply valve *9* is located between the two collars on the piston stem and moves with piston *8*. There is a port *b* through the supply valve that in open position registers with port *c* in the seat and allows air to pass into the feed-valve pipe passage *d*. Spring *10* holds the supply valve on its seat so that grit and dirt cannot work under it when there is no air pressure on the valve. When not feeding air into the brake pipe, the supply valve *9* and piston *8* are held in their normal, or closed, position, Fig. 45, by the piston spring *6*; when feeding air into the brake pipe, piston *8* and the supply valve *9* are held in their open position, Fig. 44, by an excess of main-reservoir pressure in chamber *B* over the pressure in chamber *G*.

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59. There is a quick-thread screw on the regulating nut *22* that will change the adjustment of the regulating spring *17* from 70 to 110 pounds, or to other moderate differences of pressure, when the nut is turned by the adjusting handle, which is cast solid with the nut. Stops *19* and *20* are split rings that fit around the spring box *18* and are clamped in their proper positions by the screws *21*. The regulating spring *17* unseats the regulating valve *12* and determines the pressure to be carried in the feed-valve pipe. When the pressure in chamber *L* is less than the tension of spring *17*, the diaphragm *14* is held over against the pressure in chamber *L* and the regulating valve is held off its seat, as shown in Fig. 44.

When the pressure in the feed-valve pipe reaches the standard desired, the pressure in chamber *L*, acting on the diaphragm *14*, will overcome the tension of spring *17* and move the diaphragm to the right, allowing the regulating-valve spring *13* to move the regulating valve *12* to its closed position, as shown in Fig. 45. Spring *13* holds the regulating valve *12* against the diaphragm *14* in open position, and against its seat in closed position. The diaphragm ring *15* makes an air-tight joint with diaphragm *14* against the valve body *2*, and prevents the escape of air from chamber *L* into the regulating-spring chamber.

OPERATION AND REGULATION

60. Operation. — Air from the main reservoir enters the pipe bracket at the connection *MR*, Figs. 44 and 45, flows through the passage *a* in the body of the valve to chamber *B* around the supply valve *9* and against the chamber *B* side of piston *8*. If the pressure in chamber *B* is sufficient, it will move piston *8* and valve *9* over against the tension of spring *6*. Air from chamber *B* will then flow through the ports *b* and *c* into passage *d*, and out to the feed-valve pipe through the connection *FVP* on the pipe bracket. At the same time, air from chamber *B* feeds by piston *8*, which is not an air-tight fit in its cylinder, into chamber *G*,

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and through the passage *h* into chamber *H*, thence past valve *12*, through port *k*, into chamber *L*, and out through passages *e* and *d* to the feed-valve pipe. Thus, when the feed-valve is charging the brake pipe, air passes through the valve in two ways. As the pressure in the feed-valve pipe and chamber *L* increases, it moves the diaphragm *14* to the right, compressing the regulating spring *17*. The regulating

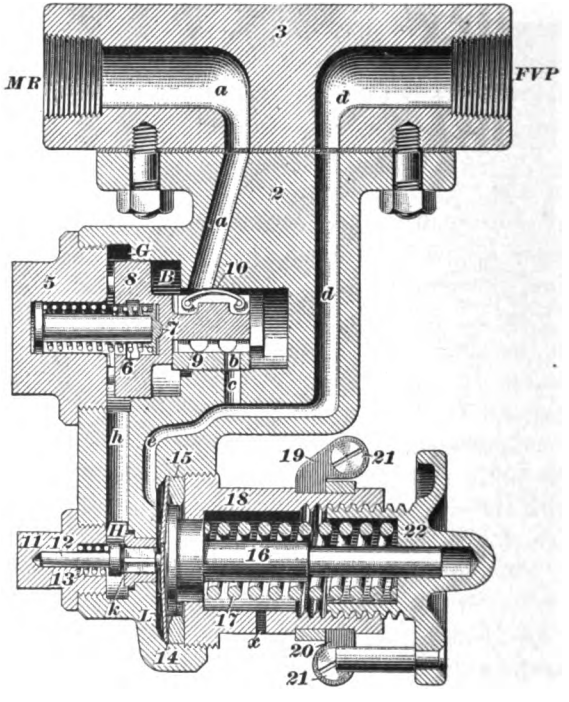

FIG. 44

valve *12* rests on the diaphragm *14*, so that when the diaphragm moves to the right, the valve *12* is also moved to the right by the spring *13*; and when the pressure in chamber *L* reaches the amount for which spring *17* is adjusted, valve *12* will be on its seat and will thus cut off the flow of air from chamber *H*, through port *k* into chamber *L*. The leakage past piston *8* will then quickly equalize the pressures in

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chambers *B* and *G*, when spring *6* will move piston *8* and valve *9* to their closed position, as shown in Fig. 45.

Any reduction in feed-valve pipe pressure will cause a like reduction in chamber *L* on the diaphragm *14*; this will allow spring *17* to move the diaphragm spindle *16* and diaphragm *14* to the left and unseat the regulating valve *12*.

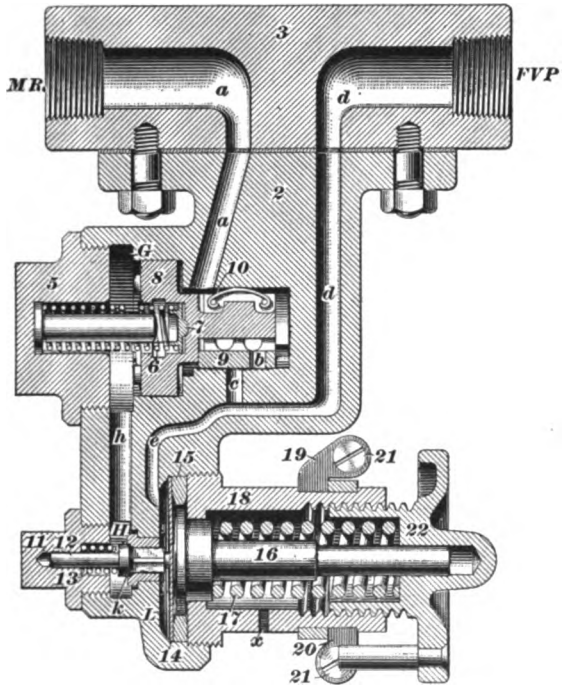

FIG. 45

This will again open communication between chambers *G* and *L*, and the pressure in chamber *G* will at once equalize with that in the feed-valve pipe. As the pressure in chamber *B* will then be greater than that in chamber *G*, it will move the piston *8* and valve *9* to open position. When the feed-valve is charging the feed-valve pipe and the pressure is rising gradually, diaphragm *14* and valve *12* will slowly move to closed position. When the regulating valve is

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partly closed, it will not permit air to flow past it as fast as the air can feed past piston *8*, and the pressure in chamber *G* will begin to build up. This will assist the spring *6* to move piston *8* and valve *9* over so as to close port *c* partly. When valve *12* begins to open or close slowly, piston *8* will likewise move valve *9* slowly to open or close port *c*.

61. Regulation.—To insure accuracy in regulating the B-6 feed-valve, it should be connected with a correct pressure gauge. The regulating nut *22*, Figs. 44 and 45, should be screwed in to increase the pressure at which the valve will close, and screwed out to reduce the pressure. To adjust this valve, first slacken screw *21* and turn the adjusting handle *22* until the valve is adjusted properly for the desired lower pressure. Then move the stop-ring *20* until it comes against the pin in handle *22* and fasten ring *20* in this position on the spring case *18* by means of screw *21*. Next, turn handle *22* until the valve is adjusted properly for the desired higher pressure and then move ring *19* around to bring the stop against the pin in handle *22* and secure it in that position with screw *21*. The pressure in the feed-valve pipe can then be quickly changed from high to low or from low to high by simply turning handle *22* so as to move the stop-pin from stop *19* to stop *20* or from stop *20* to stop *19*. If it is desired to carry a pressure between the low and the high pressure, handle *22* can be stopped at any point between the stops *19* and *20*.

C-6 REDUCING VALVE

DESCRIPTION

62. The **C-6 reducing valve** is similar to the slide-valve feed-valve used with former types of locomotive brake equipments; but, when used with the No. 14 E L equipment, it is called a *reducing valve*, because it is used to reduce the main-reservoir pressure to 45 pounds for use in the independent brake valve and the air-signaling system. When

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used with the No. 14 E L equipment, it is attached to a pipe bracket that is located in the reducing-valve pipe, Fig. 1.

63. Fig. 46 shows the C-6 reducing valve attached to the pipe bracket. Figs. 47 and 48 are conventional views, showing the ports, passages, and movable parts of the reducing valve on the same plane. As with other conventional views,

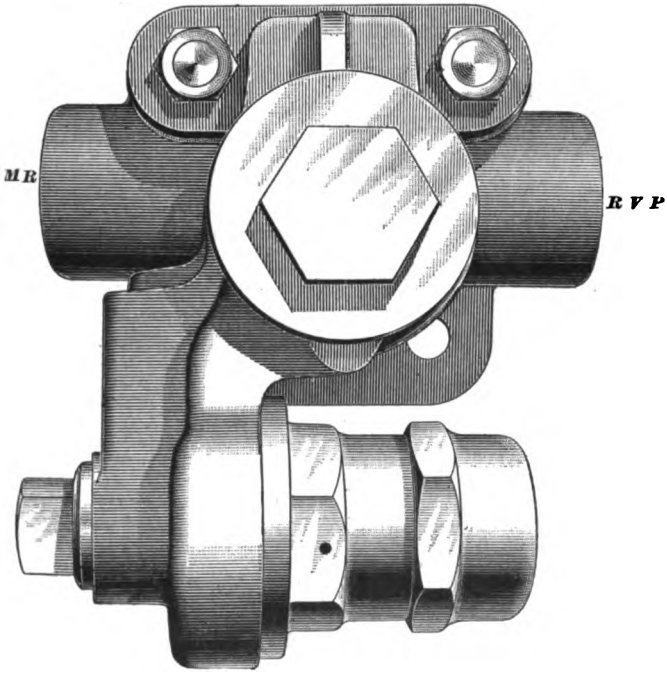

FIG. 46

these views are given simply to assist in explaining the operation of the valve. Fig. 47 shows the valve in its open position, and Fig. 48 shows it in its closed position.

The numbers and names of the parts of this valve are as follows: *2*, valve body; *5*, cap nut; *6*, piston; *7*, supply valve; *8*, supply-valve spring; *9*, piston spring; *12*, regulating valve; *13*, regulating-valve spring; *14*, regulating-valve cap

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nut; *15*, spring box; *16*, diaphragm ring; *17*, diaphragm; *18*, diaphragm spindle; *19*, regulating spring; *20*, regulating nut; *21*, check-nut.

OPERATION AND REGULATION

64. Operation. — Referring to Figs. 47 and 48, air from the main reservoir enters the pipe bracket at the connection *MR*, Fig. 46, and flows through passage *a*, Figs. 47 and 48, to chamber *B* around the supply valve *7* and against the

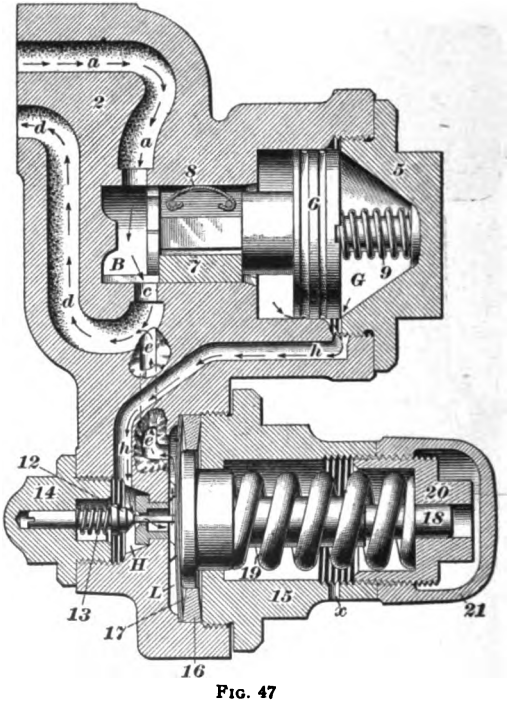

FIG. 47

chamber *B* side of piston *6*. If the pressure in chamber *L* on the diaphragm *17* is less than that for which the regulating spring *19* is adjusted, spring *19* will move the diaphragm *17* to the left far enough to unseat valve *12*. This will open communication between chamber *G* and the redu-

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cing-valve pipe through passage *h*, chambers *H* and *L*, and passages *e* and *d*. The pressure acting on the chamber *B* side of piston *6* will force this piston over to the right against the tension of the spring *9*, Fig. 47. This movement of piston *6* will also move the supply valve *7* over so as to open communication between chamber *B* and port *c*. Air from chamber *B* will then flow through the port *c* into passage *d*

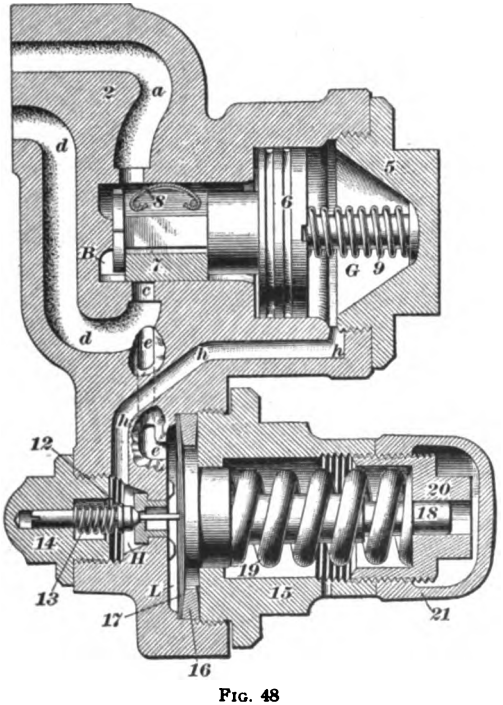

FIG. 48

and out to the reducing-valve pipe through the connection *RVP* on the pipe bracket, Fig. 46. At the same time, air from chamber *B*, Fig. 47, will feed around piston *6*, which is not an air-tight fit in its cylinder, into chamber *G*, and through passage *h* to chamber *H*, thence past valve *12* to chamber *L*, and out through passages *e* and *d* to the reducing-valve pipe.

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65. As the pressure in the reducing-valve pipe and chamber *L* increases, it moves the diaphragm *17* to the right, compressing the regulating spring *19*. The regulating valve *12* is held against the diaphragm *17* by the spring *13*, so that when the diaphragm moves to the right, valve *12* is also moved to the right by the spring *13*; and when the pressure in chamber *L* reaches the amount for which spring *17* is adjusted, valve *12* will be on its seat. This will cut off the flow of air from chamber *H* to chamber *L* past the valve *12*. Then, the leakage past piston *6* will quickly equalize the pressures in chambers *B* and *G*, when spring *9* will move piston *6* and valve *7* to their closed position, as shown in Fig. 48. With valve *7* in its closed position, no air can pass from chamber *B* through port *c* to the reducing-valve pipe.

Any reduction in pressure in the reducing-valve pipe will cause a similar reduction in chamber *L* on the diaphragm *17*. This will allow spring *19* to move the diaphragm *17* to the left, thereby unseating valve *12*, which will again open communication between chambers *G* and *L* through passage *h* and chamber *H*. The pressure in chamber *G* will then quickly reduce to that in the reducing-valve pipe, and as the pressure in chamber *B* is greater than that in chamber *G*, it will move piston *6* and valve *7* to open position, Fig. 47.

66. Regulation. — If the reducing valve does not regulate the reducing-valve pipe pressure to the proper amount (45 pounds), it can be adjusted by means of the regulating nut *20*. If it maintains a pressure below 45 pounds in the reducing-valve pipe, the regulating nut *20* should be turned slowly until the tension of the regulating spring *19* is sufficiently increased to give the proper regulation. If it maintains a pressure greater than 45 pounds in the reducing-valve pipe, the regulating nut *20* should be turned so as to reduce the tension of the regulating spring *19* the amount necessary to cause the valve to give the proper pressure.

In order to turn the regulating nut *20*, the check-nut *21* must first be removed. After the regulating spring has been properly adjusted, the check-nut must be replaced.

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If the independent brake valve is placed in application position, the red hand on the large duplex air gauge, Fig. 1, will usually show the pressure maintained by the reducing valve.

TYPE C AND TYPE B-2 STRAINER AND CHECK-VALVE

DESCRIPTION

67. There are two forms of the combined strainer and check-valve used with the No. 14 E L equipment. One, the **C strainer and check-valve,** is used in connection with the by-pass arrangement on a dead locomotive, or a locomotive with disabled air compressors, to pass air from the brake pipe to the main-reservoir pipe; the other, the **B-2 strainer and check-valve,** is used in connection with the air-signal system. Both forms are shown in their proper location in the piping diagram, Fig. 1.

68. Referring to Figs. 49 and 50, the numbers and names of the parts of the type C and the type B-2 strainer and check-valve are as follows: *2*, valve body; *3*, cap nut; *4*, check-valve; *5*, check-valve spring; *6*, valve cap; *7*, perforated strainers; *8*, curled hair; *9*, union swivel; *10*, union nut; *11*, union gasket; and *12*, a choke fitting.

OPERATION

69. When the C strainer and check-valve, Fig. 49, is in use as a by-pass on a dead locomotive, brake-pipe air enters at the connection *BP* and passes through the strainers *7* and the curled hair *8* to the space under valve *4*. The spring *5* in the valve has a tension that will hold check-valve *4* on its seat until the pressure below valve *4* is about 20 pounds higher than that above it. With a pressure of 70 pounds in the brake pipe, the spring *5* will allow a pressure of about 50 pounds in the main reservoir on a dead locomotive to operate its brakes by means of the distributing valve.

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The choke plug in the outlet *MR* prevents air from flowing out of the brake pipe so fast as to interfere with the release of the train brakes or cause them to stick. The check-valve *4*

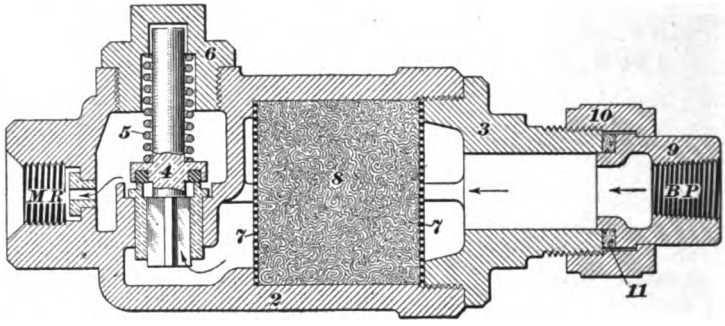

FIG. 49

prevents any air from passing back into the brake pipe from the main-reservoir pipe when a brake-pipe reduction is made, so that the operation of the train brakes will not be interfered with. The purpose of the cut-out cock used with the by-pass is to cut out the by-pass arrangement when the air compressor on that locomotive is furnishing air for its own brakes.

70. With the B-2 strainer and check-valve, Fig. 50, used in connection with the air-signaling system, air enters at the reducing-valve pipe connection, passes through the strainers *7* and curled hair *8*, then past the check-valve *4*,

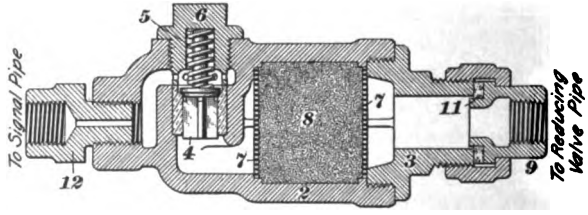

FIG. 50

and through the choke fitting to the signal pipe. In this case, the spring *5* has a very light tension, so that there is very little difference of pressure on the upper and lower

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sides of valve 4. For this service, a special choke fitting somewhat larger in size but having a smaller bore than the one used in the C strainer and check-valve, Fig. 49, is placed in the union close to the check-valve. This union choke restricts the flow of air into the signal pipe, so that the car discharge valve can reduce the signal-pipe pressure when operating the signal apparatus. The check-valve 4 prevents air from flowing back from the signal pipe and causing the whistle to blow when the locomotive brakes are applied through the independent brake valve.

CARE, MAINTENANCE, AND DEFECTS

BRAKE VALVE

71. Brake-Valve Handle Works Hard.—If the handle of either the automatic or the independent brake valve does not operate easily, the rotary valve, or rotary-valve-key gasket is likely dry from lack of lubrication. To remedy this trouble, when the brake system is charged, close the cut-out cock in the brake pipe below the brake valve, also close both of the cut-out cocks in the pipes leading from the main reservoirs to the main-reservoir pipe connecting the brake valves. Operate the brake valves to remove all pressure from them, then remove the oil plug in the automatic brake-valve body, fill the hole with good valve oil, and move the brake-valve handle from full release to emergency position and back to release position a few times to work the oil between the rotary and its seat. Again fill the oil hole and replace the plug. Next, remove the screw plug from the top of the rotary-valve key, fill the hole in the key with oil, push down on the key, and move the handle a few times; then again fill the hole with oil and replace the plug. Treat the independent brake valve in the same manner.

72. Brake-Valve Tests.—To test for a leaky rotary valve in the automatic brake valve, close the cut-out cock in the brake pipe below the brake valve, place the automatic

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brake-valve handle in lap position, and start the compressor. A leak past the rotary valve into the brake pipe will be indicated by a blow at the brake-pipe exhaust port or by the black hand on the large air gauge moving up. If the rotary or the valve-seat lower gasket allows main-reservoir air to leak into chamber *D* it will be shown by the black hand on the large air gauge moving up, but it will not cause a blow at the brake-pipe exhaust port.

To make the test when the brake system is charged, place the brake-valve handle in service position and discharge all the air from the brake pipe; then close the cut-out cock in the brake pipe under the brake valve and place the brake-valve handle in lap position. If a blow starts at the brake-pipe exhaust port, it indicates a leak past the rotary valve into the brake pipe; if the black hand on the large air gauge shows an increase in pressure, it indicates a leak past the rotary valve or the valve-seat lower gasket, into chamber *D*. If the brake-cylinder gauge shows an increase in pressure or if an intermittent blow occurs at the safety valve on the distributing valve, it indicates a leak into the port or passage leading to the distributing-valve application-cylinder pipe.

73. If the rotary valve in the independent brake valve is leaking, it will most likely cause a blow at the brake-valve exhaust port, and when the brake valve is in lap position after a partial independent application, a leak past the rotary into the application-cylinder pipe will cause the brake-cylinder pressure to increase to the amount for which the C-6 reducing valve is set.

If, with the automatic brake valve in release, running, or holding position, there is a constant blow at the brake-pipe exhaust port, it indicates that the brake-pipe exhaust valve is held from its seat by foreign matter or that the valve or its seat is cut. If the trouble is due to the former cause, it may be possible to dislodge the foreign matter by tapping the brake valve while making a service application or by removing the exhaust plug and using a thin, pointed piece of wood to remove the dirt. If the trouble is due to the valve or its

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seat being cut, the equalizing valve and its seat will have to be reground to permit the valve to make a tight joint.

74. To determine whether a leak is from the brake valve or from the distributing valve, open the unions in the pipes leading from the brake valve to the distributing valve, after placing both brake-valve handles in lap position: then, if air blows out of a pipe at the open union when the port leading to that pipe should be closed, it will locate the leak. It will usually take an inspection to determine whether the leak is across the body gaskets or past the rotary valve.

If the leak is supposed to be from the brake pipe or chamber *D* into one of the pipes, discharge all of the air from the brake pipe by placing the automatic brake valve in service position and then place the brake-valve handle in lap position; if that stops the leak at the open union, and it begins again when the brake pipe is charged up, look for a leak past the body gaskets.

If the B-6 feed-valve is dirty or gummed up and there is an excessive brake-pipe leakage, the sluggish action of the feed-valve might allow brake-pipe pressure to reduce 4 or 5 pounds before it opens to supply the leakage. This would probably cause the locomotive brakes to apply each time the feed-valve closed and release again when the feed-valve opened, which would produce a mild blow at short intervals at the emergency exhaust port of the automatic brake valve, while the automatic and independent brake valves are in running position. If the independent brake valve is placed in lap position, the locomotive brakes will remain applied and the blow at the emergency exhaust port of the automatic brake valve will cease. The fluctuation of the black hand on the small air gauge will indicate the opening and closing points of the feed-valve.

75. If the air from either the main reservoir or the brake pipe can leak into the application chamber or cylinder of the distributing valve, it will make a steady blow at the emergency exhaust port of the automatic brake valve when the equal-

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izing valve in the distributing valve is in release position and both brake valves are in running position.

A blow at the emergency exhaust port of the automatic brake valve, while it is in running position, might be due to a leak past the equalizing valve in the distributing valve or past the gasket between the distributing valve and its divided reservoir, or past the rotary valves in the brake valves. To locate the cause for this blow, cut out the main-reservoir and brake-pipe air from the distributing valve and drain all air from the distributing valve. Then, if the blow continues it must come from one of the brake valves, but if the blow stops look for the cause in the distributing valve.

76. Leak from Passage *A* Into Chamber *D*.—If the gasket that is between the rotary-valve seat and bottom case of the brake valve leaks so that air can pass from passage *A* into chamber *D* equal to or greater in volume than the discharge through the preliminary-exhaust port *e*, no reduction in chamber-*D* pressure can be made with the rotary valve in service position, and the equalizing piston will not rise, hence no reduction in brake-pipe pressure will be made; also, no excess pressure will be indicated by the large air gauge. If, in addition to the above leak, air can leak past the equalizing piston into the brake pipe, it will increase the brake-pipe pressure and tend to release the brakes when the brake valve is in lap position after the brakes have been applied.

C-6 REDUCING VALVE

77. In order to obtain the best service from the independent-brake applications and the signal system it is important that the C-6 reducing valve be kept clean and properly adjusted. If the reducing valve leaks or is adjusted for a pressure that is too high, the pressure in the locomotive brake cylinders may be increased above the desired amount when independent-brake applications are being made. If it is adjusted for a pressure that is too low, the pressure in the signal system and for use in the independent brake valve will

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not be raised to the amount necessary to obtain the best service. If, when the brake system is charged, the independent brake valve is held in quick-application position the red hand on the small air gauge will indicate approximately the pressure for which the reducing valve is set.

DISTRIBUTING VALVE

78. Care and Maintenance.—In order that the distributing valve may work properly, it is essential that the valves and pistons be kept well lubricated and free from dirt. The distributing valve and its reservoir should be regularly drained and the pipe connections be kept tight. If the distributing valve is to be repaired or cleaned and tested, it should be removed from the double-chamber reservoir by removing the nuts from the reservoir studs. As all the pipe connections are made to the double-chamber reservoir, removing the valve in this manner does not interfere with the pipe joints. If the gasket between the distributing valve and the reservoir becomes torn or injured while removing the valve, a new one must be applied, as a very slight leak across this gasket, from one port to another, will interfere seriously with the operation of the valve. When the pipes are first installed or new ones applied, they should be blown out with steam or compressed air before the valves are attached, to clear them of foreign matter.

If the distributing valve becomes dry from lack of lubrication, or if it becomes corroded or very dirty, a greater difference of pressure will be required to overcome the excessive friction and operate the movable parts.

If the pipes and passages become corroded or very dirty, the locomotive brakes will not apply and release as promptly as when they are clean. If, when the brake system is fully charged and a 5-pound service reduction is made, the locomotive brakes fail to apply, it is most likely due to excessive friction in the working parts of the distributing valve, and they should be removed, cleaned, and lubricated. Sometimes the equalizing-piston packing ring sticks in its groove

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and prevents the equalizing piston from being moved by variations in brake-pipe pressure.

79. Leaks and Defects.—When testing for distributing-valve leaks or for leaks into the pipes leading to this valve, 70-pound brake-pipe pressure should be used, as with this pressure the point where the leak is occurring can be more easily determined than when a brake-pipe pressure of 110 pounds is used. If air discharges from the brake-cylinder exhaust port of the distributing valve when the brake is applied, look for leaks between the distributing valve and the brake valves that will reduce the pressure in the application cylinder. If the brake leaks off without this exhaust, there are leaks from both the application cylinder and the brake cylinders. To test for these leaks, apply the brake in full and try all the joints with the flame of a torch, or, if possible, apply soapsuds to the suspected parts. In order to keep all joints under pressure during this test, apply the independent brake and let the independent brake valve remain in slow-application position.

A leak in the application cylinder, application-cylinder cover gasket, or any place that will allow application-cylinder pressure to escape to the atmosphere will allow the application piston to move the exhaust valve *16* so as to exhaust brake-cylinder air. This may take place during a graduated application with either the independent or the automatic brake valve, but not if the automatic brake valve is placed in emergency position or the independent brake valve is placed in application position.

80. If, after an automatic application has been made, the automatic brake valve is placed in release or in holding position and the brake releases, look for a leak from the application cylinder or its connections. If the brake releases after an independent application but remains applied after an automatic application, look for a leak in the distributing-valve release pipe between the distributing valve and the brake valve. A leak in the application-cylinder pipe, cap,

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or cap gasket will allow either an independent or an automatic application to release.

A leak into the application-cylinder pipe will build up a pressure in the application cylinder and cause the application piston to apply the brakes when the ports in either the independent or the automatic brake valve are lapped; or, during a graduated application, the brakes will apply harder. These leaks may occur at the brake valve, across the distributing-valve gasket into the application chamber, or under the equalizing valve *31*.

A leak out of any part of the release pipe will not affect the action of the distributing valve during an automatic emergency application, as the port leading to this pipe is then lapped by the equalizing slide valve. But when an automatic-service application is being made, the equalizing and graduating valves open communication between the brake pipe and the distributing-valve release pipe; hence a leak from the release pipe would continue to reduce brake-pipe pressure as long as the equalizing piston remained in service position. If the equalizing valve is in release position when a graduated independent application is made, air from the application cylinder can flow through the open exhaust port to the release pipe and escape through the leak. A leak out of this pipe will not release the brake if the independent brake valve is left in application position, provided that the brake valve can supply the air as fast as it leaks away.

81. To locate the trouble if the brake-cylinder pressure increases after a partial service application is made, charge the brake system and make a 10- or 12-pound service reduction with the automatic brake valve; then lap the valve and note the pressure on the brake-cylinder gauge. If the brake-cylinder pressure increases to 50 pounds and remains constant, it is very apt to be due to brake-pipe leakage. Brake-pipe leakage in the distributing valve may be due to a defective equalizing cylinder-cap gasket that allows brake-pipe air to pass from chamber *p* to passage *m*, or if a quick-action cylinder cap is used, it may be due to a leak past the cylinder-

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cap gasket or to a defective slide valve *48* that allows brake-pipe air to pass into passage *m*. Also, with the equalizing and graduating valves in service position, a leak from the distributing-valve release pipe will tend to reduce brake-pipe pressure. A continued leak from the pressure chamber into the application chamber would tend to increase brake-cylinder pressure. Also, this leak would tend to cause the equalizing piston of the distributing valve to move to release position, but the brake would not release because the automatic brake valve would have the exhaust closed.

If, after a 10- or 12-pound reduction is made, the brake-cylinder pressure rises to 45 pounds, the pressure for which the reducing valve is set, and remains at this pressure, it may be due to a leaky rotary valve in the independent brake valve. If the brake-cylinder pressure raises even above the equalizing point—50 pounds pressure—and a discharge of air is heard at the safety-valve exhaust, it indicates a leak of main-reservoir air into the application cylinder. This may be due to a leaky rotary valve in the automatic brake valve, allowing main-reservoir air to get into the port that leads to the application-cylinder pipe, or to a leak past the gasket between the distributing valve and its reservoir.

82. If air can leak from either the main reservoir or the brake pipe to the application cylinder or chamber, it will tend to cause a steady blow at the emergency exhaust port of the automatic brake valve if the independent and the automatic brake valves are in running position. When they are not in running position, it will build up a pressure and apply the locomotive brakes. A steady blow at the automatic brake valve emergency exhaust port, when the valve is in running position, usually denotes a leaky equalizing valve *31*. However, the leak may be due to a defective brake valve or to a defective gasket between the distributing valve and its reservoir. To locate the cause of this blow, close the distributing-valve cut-out cock in the main-reservoir supply pipe and the brake-pipe cut-out cocks under the brake valves at both ends of the locomotive to prevent any air

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entering the distributing valve from these sources; then drain all air from the distributing valve. If the blow continues, the air is coming from one of the brake valves. If it stops, the cause of the blow will be found in the distributing valve; or the part that is at fault can be discovered by disconnecting the application-cylinder pipe and the distributing-valve release pipe at the unions near the distributing valve. Air will escape from the pipe that is attached to the defective valve.

Brake-pipe leaks will have the same effect on the distributing valve that they have on a triple valve; that is, they will apply the brake harder when the automatic brake valve is in lap position.

83. Broken Equalizing-Piston Graduating Spring. If the locomotive brake applies quick action when only a partial service application is made and the brake-cylinder gauge shows 65 pounds pressure, look for a broken equalizing-piston graduating spring.

84. Broken Application-Piston Graduating Spring.—When the brakes are applied with a graduated automatic application, a succession of *quick* exhausts from the brake-cylinder exhaust of the distributing valve indicates a broken application-piston graduating spring.

85. Leaky Graduating Valve.—A leaky graduating valve will affect the operation of the distributing valve only during a graduated automatic application. It will then tend to cause the equalizing piston, slide valve, and graduating valve to move to release position; but the brake will not release, because the automatic brake valve is in lap position and thus prevents the escape of application-cylinder air. If the brake pipe leaks an equal amount, the brake will continue to apply harder until the pressure in the application cylinder and chamber equalizes with that in the pressure chamber. In order to allow the equalizing piston to move to release position, the pressure-chamber pressure must reduce faster than brake-pipe pressure.

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BROKEN OR LEAKY PIPES

86. To obtain the best results from the E L equipment, it is necessary that all pipe joints be kept tight and free from leaks, since leaky or broken pipes will interfere with or prevent the operation of the locomotive brakes. In some cases, when serious leaks develop, or pipes are broken off, the pipes may be plugged or blind joints made in the unions to prevent the escape of air, and the brake then operated with other pipes.

A leak in the main-reservoir pipe will not interfere with the operation of the brakes, provided the compressors can furnish sufficient air to overcome the leak. If this pipe should break off at a point between the main reservoir and the branch leading to the distributing valve, it will prevent the operation of the locomotive brakes. If it breaks off at a point in the branch pipe leading to one of the automatic brake valves, the opening in the pipe can be plugged to prevent the escape of main-reservoir air, and the locomotive brakes operated by means of the other automatic brake valve or by either of the independent brake valves.

87. If the pipe leading from the main-reservoir supply pipe to the distributing valve breaks off at the distributing valve, the locomotive brakes will not operate, because the supply of air for the locomotive brake cylinders passes through this pipe. In such a case, however, it would be possible to supply air to the locomotive brake cylinders through the independent brake valve. In order to do this, it would be necessary to close the distributing-valve cut-out cock to prevent the escape of main-reservoir air, plug the opening in the broken pipe next to the distributing valve, remove the application piston from the distributing valve, and plug the brake-cylinder exhaust port. If the independent brake valve is then placed in application position, air entering the application cylinder of the distributing valve will pass to the brake cylinders and apply the locomotive brakes. To release the locomotive brakes, move the independent brake valve to

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release position; this will allow the air from the locomotive brake cylinders to pass through the application-cylinder pipe and the independent brake valve to the atmosphere. It might also be possible to apply the locomotive brake by placing the automatic brake valve in emergency position. This would allow main-reservoir air to pass through the application-cylinder pipe and the distributing valve to the locomotive brake cylinders. But in either case the operation of the brakes would be much slower on account of the small opening in the brake valves through which the air must pass to and from the brake cylinders.

If the brake-cylinder pipe breaks off between the distributing valve and the brake cylinders, the locomotive brake cannot be operated. Stop-cocks are sometimes placed in the branch pipes to the brake cylinders so that if the break in the brake-cylinder pipe occurs between the brake cylinders and their respective cut-out cocks, the cut-out cock to that brake cylinder can be closed to prevent the escape of air through the broken pipe, and allow the other brake cylinders to receive air.

88. If the pipe that connects the brake pipe to the distributing valve breaks off, the distributing valve cannot be operated automatically by the automatic brake valve; but it can be operated to apply and release the locomotive brakes by means of the independent brake valve, or to apply the brakes by placing the automatic brake valve in emergency position. If the locomotive is coupled to a train, plug the openings in the broken pipe to prevent air from escaping; then, the train brakes can be operated as usual by means of the automatic brake valve, and the locomotive brakes can be operated by means of the independent brake valve. If the locomotive is run light, the cut-out cock in the brake pipe under the automatic brake valve can be closed, or the automatic brake valve carried in lap position in order to prevent the escape of air at the broken pipe, and the locomotive brakes, under the condition, may be operated by means of the independent brake valve.

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89. If the distributing-valve release pipe breaks off, it will not interfere with an automatic application of the brakes; but the locomotive brakes cannot be held on when the automatic brake valve is placed in release or holding position, because air from the distributing-valve exhaust port will pass out at the broken pipe when the distributing valve is moved to release position by the increase in brake-pipe pressure. Also, when an automatic service application is made, air from the brake pipe passing into the release pipe can escape through the break in the pipe. This will increase the reduction in brake-pipe pressure and tend to apply the brakes harder than intended, or, if a quick-action cylinder cap is used, it might apply the brakes quick action. If the break occurs in the branch leading to one of the brake valves, the opening in the pipe can be plugged and the brake operated by the other automatic brake valve or by either independent brake valve. If the break occurs in the branch leading to the distributing valve and it is desired to operate the locomotive brakes with the independent brake valve, the opening at the release pipe next to the distributing valve can be plugged, or else an automatic application can first be made, so that the equalizing valve will close the distributing-valve exhaust port. It is best not to plug the opening; then, when an automatic application and release is made, the locomotive brakes can be released without the aid of the independent brake valve, and, if desired to hold the locomotive brakes on while releasing the train brakes, the independent brake valve can be held in quick-application position. Also, if this opening is not plugged and the locomotive is the following one of a double header, the leading motorman can release its brakes. If the opening is plugged in the branch leading to the distributing valve, the motorman of the locomotive with the plugged pipe will have to release the locomotive brakes by placing the independent brake valve in release position.

90. If the application-cylinder pipe breaks off at a point between the brake valve and distributing valve, the locomotive brakes cannot be applied with either the automatic

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or the independent brake valves. In such a case, the opening in the pipe next to the distributing valve should be plugged to prevent the escape of air from the application cylinder. The locomotive brakes can then be applied and released by either of the automatic brake valves, and if the brake is so located that the plug does not cut out both brake valves, the brakes can be applied and released by one of the independent brake valves.

91. If the reducing-valve pipe breaks off in the branch close to the reducing valve, the locomotive brakes cannot be applied by either of the independent brake valves, but can be applied with an automatic application and released with either the automatic or the independent brake valve. However, the opening in the broken pipe next to the brake valve should be plugged; also, the opening next to the reducing valve should be plugged, or the tension taken off of the regulating spring in the reducing valve to prevent air escaping from the broken pipe. Then, before making an automatic application, the independent brake valve should be placed in application position so that, when the brake is being applied, air from the application cylinder of the distributing valve can pass to the space above the rotary valve in this brake valve and thus prevent the rotary valve from being raised from its seat. The independent brake valve must be moved back to running or release position in order to allow the locomotive brakes to release. An easier method of overcoming this defect is to remove the tension from the reducing-valve regulating spring to prevent the escape of air at the broken pipe, then place a blind gasket in the union where the application-cylinder pipe connects with the brake valves. This will prevent the locomotive brake from being released by means of the independent brake valve, but will not interfere with an automatic application, except that the main-reservoir air cannot pass to the application cylinder of the distributing valve when the automatic brake valve is in emergency position. However, the independent brake valve must be in running position in order that the locomotive

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brakes may be released through the automatic brake valve. If the break occurs in the branch leading to one of the brake valves, the opening can be plugged and the locomotive brakes operated by means of the other independent brake valve.

92. If the equalizing-reservoir pipe or the pipe leading to the black hand of the large duplex air gauge breaks off, it would reduce the pressure in chamber *D* of the automatic brake valve, which would allow the equalizing piston to open the brake-pipe exhaust valve and apply the brakes, thus rendering the equalizing-discharge feature of the brake valve useless until the leak is stopped. If the locomotive is not handling a train, lap the automatic brake valve and operate the locomotive brakes by means of the independent brake valve. However, if it is desired to operate train brakes in conjunction with the locomotive brakes and the break occurs in the pipe leading to the air gauge, plug the opening in the pipe next to the brake valve. This will cut out the equalizing-reservoir gauge but will not interfere with the working of the brake valve. If the leak occurs in the equalizing-reservoir pipe, plug the opening in the pipe next to the brake valve, also the opening in the brake-pipe exhaust fitting and use the automatic brake valve carefully in emergency position to make automatic service applications. In all other respects, operate the brake valve as usual.

When making service applications by placing the automatic brake valve in partial emergency position, care must be taken not to open the exhaust port too wide or too rapidly, as it might result in an emergency application of the brakes. The exhaust port must be opened gradually and just enough to reduce brake-pipe pressure at the same rate it would reduce through the service exhaust port. Also, care must be taken to close the exhaust port gradually, because, if it is closed too quickly, the flow of air through the brake pipe might increase the brake-pipe pressure on the head cars of the train sufficiently to release some of the head-end brakes.

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BLOWS

93. A constant blow at the brake-cylinder exhaust of the distributing valve, when the brakes are released, may be due to a leak of main-reservoir air past the application valve *5* or the gasket between the distributing valve and its reservoir; or it may be due to a brake-pipe leak in this gasket or in the equalizing-cylinder-cap gasket that allows air to pass into passage *m*, or the emergency slide valve in the quick-action cylinder cap. If it is a leak of main-reservoir air, the blow will gradually decrease until stopped, when the distributing-valve cut-out cock in the main-reservoir supply pipe to the distributing valve is closed. If the leak is from the brake pipe, the blow will continue after the distributing valve cut-out cock is closed. A leaky exhaust valve in the distributing valve will cause a blow at the brake-cylinder exhaust only while the brake is applied. A leak past the application valve *5*, when the locomotive brake is applied and the distributing valve is in lap position, will continue to increase the pressure in the exhaust-valve chamber until the pressure in this chamber overcomes that in the application cylinder. Then the application piston *10* will move the exhaust valve over toward release position, and allow air to escape through the brake-cylinder exhaust port just fast enough to keep the pressure in the exhaust-valve chamber equal to that in the application cylinder, or, if the pressure in the exhaust-valve chamber is reduced slightly below that in the application cylinder, the exhaust valve will again close the brake-cylinder exhaust ports. This action of the distributing valve will take place each time the leak increases the pressure in the exhaust-valve chamber above that in the application cylinder.

94. A defective equalizing-cylinder-cap gasket that allows air to pass between the brake pipe and passage *m* will not only cause a blow at the brake-cylinder exhaust while the brake is released, but, when the brake-pipe pressure has been reduced considerably below the amount necessary to apply the brake in full and the automatic brake valve is

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on lap, brake-cylinder air will pass into the brake pipe, as will be indicated by the brake-pipe gauge. As the brake-pipe pressure increases above the pressure in chamber *D* of the automatic brake valve, the equalizing piston will rise and cause a blow at the brake-pipe exhaust. A leak past the check-valve in the quick-action cylinder cap would have the same effect.

TESTING BRAKE-CYLINDER LEAKAGE AND THE SAFETY VALVE

95. To test for brake-cylinder leakage, first apply the brake; then close the distributing-valve cut-out cock in the supply pipe to the distributing valve, Fig. 1, and the reduction in brake-cylinder pressure will be indicated by the brake-cylinder gauge. If a cut-out cock is provided for each brake cylinder, the amount of leakage in any individual brake cylinder can be closely determined by closing all the brake-cylinder cut-out cocks but the one to the brake cylinder that you want to test, and note the fall of pressure as indicated by the brake-cylinder gauge.

96. The safety valve is connected to the application cylinder of the distributing valve in all positions of the equalizing valve and the graduating valve except service-lap position. To determine whether or not the safety valve is properly adjusted, place the automatic brake valve in emergency position and leave it there, then note the pressure shown on the brake-cylinder gauge when the safety valve opens.

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TRAIN AIR-SIGNALING SYSTEM

ARRANGEMENT OF APPARATUS

97. The general arrangement of the train **air-signaling apparatus** on the locomotive is shown in Fig. 1. The locomotive and each of the cars are piped with a $\frac{3}{4}$-inch pipe, which is connected between cars by means of hose, so that when all the hose are coupled, the signal-pipe line extends throughout the entire train.

A car discharge valve, Figs. 1 and 52, is provided on each car. This is usually located outside the car above the door, and is piped to the train signal pipe. Sometimes, however, it is placed inside the car above the door, to guard against the valve being clogged in winter. The former position is preferable, however, as the chances of clogging are small, and the annoyance caused by the sharp sound of discharging air every time the valve is opened to make signals is avoided.

A signal cord is attached to the lever of the discharge valve, and one end extends across the platform and is fastened in a suitable manner to the hood, while the other end extends through the car and is fastened to the hood on the other end of the car. This cord enables the discharge valve to be operated from any part of the car.

98. The air-signal system on the locomotive, Fig. 1, consists of the C-6 reducing valve, the B-2 strainer and check-valve, the signal valve, the car discharge valve, the signal whistle, and the necessary piping to convey the air to these parts. The C-6 reducing valve reduces the main-reservoir pressure to 45 pounds, for use in the independent brake valve and also in the signal line. Air from this reducing valve passes through the B-2 strainer and check-valve, where its pressure is further reduced by means of the check-

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valve spring in the combined strainer and check-valve, so that a pressure of about 40 pounds is supplied to the signal system.

A $\frac{3}{8}$-inch pipe leads from the B-2 strainer and check-valve to the $\frac{3}{4}$-inch signal pipe, which extends from one end of the locomotive to the other and has hose connections to connect with the signal line on the cars. Cut-out cocks are provided at each end of the cars and locomotive to govern the passage of air from one car to the other or to prevent the escape of air at either end of the train when the front and rear cocks are closed. A branch leads from the signal line at each end of the locomotive to a signal valve.

99. A signal whistle, Fig. 1, is located at each end of the locomotive cab, as close to the motorman as practicable. The whistle is piped to the signal valve, and it is the operation of the signal valve that causes the whistle to blow. A stop-cock is provided in the whistle pipe to cut out one whistle if desired, when the locomotive is being operated from the other end.

To transmit a signal to the motorman, the conductor pulls the signal cord in one of the cars. This opens the discharge valve on that car and allows some of the air in the main signal pipe to escape to the atmosphere, thus reducing the signal-pipe pressure. The reduction in pressure operates the signal valve on the locomotive, which consequently discharges a small quantity of air through the signal whistle in the cab, thus causing it to sound a short blast. Each time the cord is pulled, the signal whistle gives a blast.

DESCRIPTION OF APPARATUS

SIGNAL WHISTLE

100. The **signal whistle** is shown in Fig. 51. The bowl *1* forms the base of the whistle and connects with the whistle pipe at X. The passage a' and port a form a passage

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from the whistle pipe into chamber *A*. The disk *2* deflects the escaping air and makes it strike the edge of the bell *3* of the whistle. The tone of the whistle depends on the depth of chamber *B*. The check-nut *4* and cap nut *5* act as lock-nuts to lock the bell of the whistle in position after it has been adjusted.

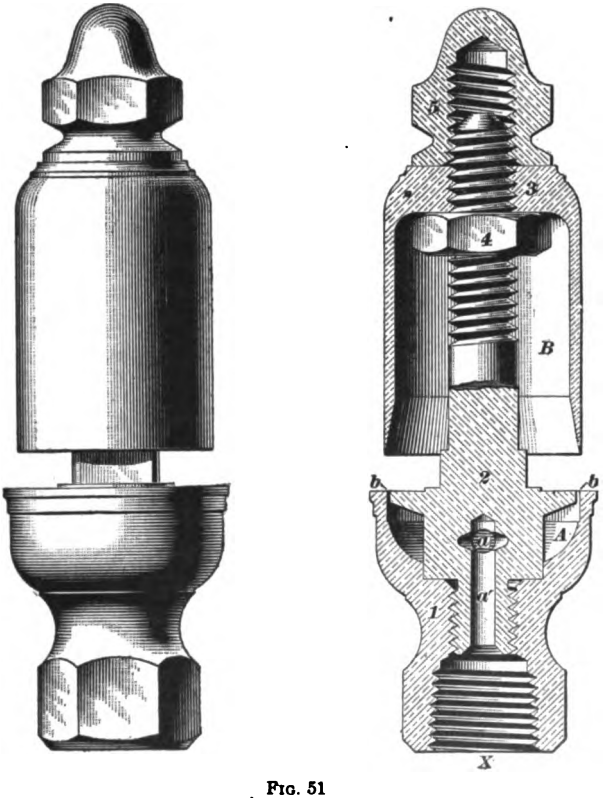

FIG. 51

An imperfect adjustment of the whistle bell, or its bowl being filled with dirt, will either cause the whistle to work badly or prevent it from working at all. No set rule can be given for the adjustment of the whistle, but it must be so adjusted as to give the best sound. To adjust the whistle, slack off nut *5* and turn the whistle bell and check-nut *4* up

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or down until the desired tone is obtained; then screw the cap nut *5* down to lock the whistle bell in position. Care should be taken not to locate the whistle near one of the cab windows where a current of air will be liable to blow across it, as a strong current of air blowing across the whistle will render it inoperative.

CAR DISCHARGE VALVE

101. A sectional view of the **car discharge valve** is shown in Fig. 52. The discharge valve is shown at *3*; the discharge-valve spring that holds this valve up against its seat at *4*; the lever, or handle, to which the signal cord is attached at *5*; and the stop-pins at *6*. There is a union connection at *a* to which the branch pipe from the signal pipe is connected, while the exhaust port *b* leads to the atmosphere.

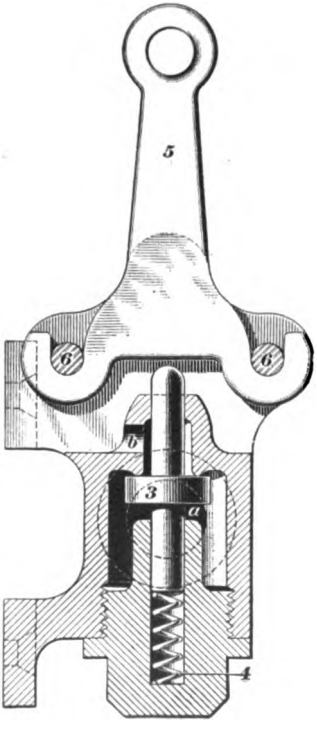

FIG. 52

102. Operation of Valve. When the signal cord on either side of the car discharge valve is pulled, the lever *5* is caused to strike the stem of the discharge valve *3* and force the valve from its seat. Air from the signal pipe then passes through the branch pipe and out to the atmosphere through the union connection *a* and the port *b*, causing a reduction in signal-pipe pressure. As soon as the signal cord is released, the spring *4* forces the discharge valve to its seat again and stops the discharge of air from the signal pipe.

The branch pipe to the discharge valve is fitted with a strainer at the point where it connects with the main signal pipe, and a cut-out cock is located near the discharge valve.

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The former prevents dirt from reaching the discharge valve, and the latter enables the discharge valve to be cut out in case it is disabled. The handle of the cut-out cock stands parallel with the pipe when the discharge valve is cut out, and at right angles to it when cut in. Also, the cut-out cocks in the signal pipe on either side of the signal hose are closed when the handles stand parallel with the pipe, and open when at right angles to it. The couplings in the signal hose are of a different size from those in the air-brake hose, so the signal hose and brake hose cannot be coupled by mistake.

SIGNAL VALVE

103. The **signal valve** is shown in Fig. 53. The signal pipe connects at X, and a pipe leads from Y to the

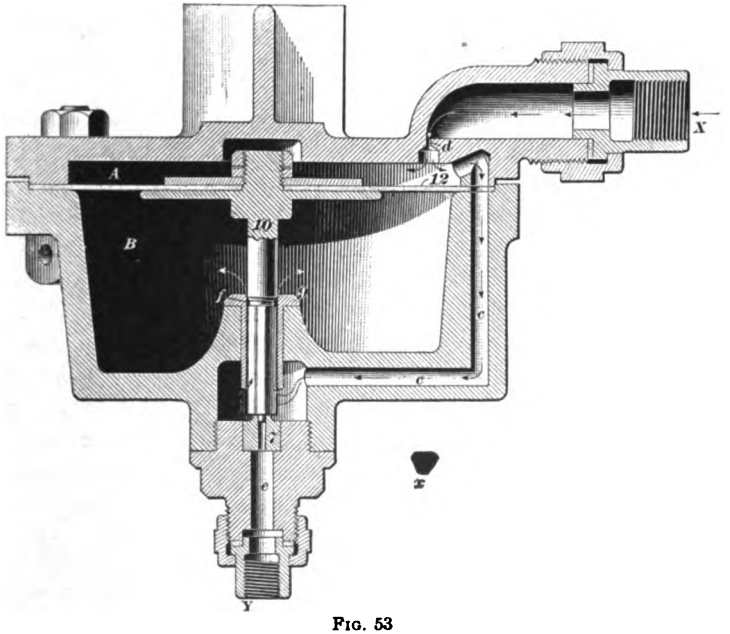

FIG. 53

whistle. The valve body is divided into two chambers A and B by a rubber diaphragm *12*, which is attached to and

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operates the diaphragm stem *10*. This stem extends through the bushing *9*, and its end forms a valve (with its seat in bushing *7*) that controls the passage *e* leading to the whistle. A small portion of the stem *10* fits the bushing *9* snugly; below this a groove *f* is cut around the stem. Below groove *f* the stem is milled to a cross-section like that shown at *x*, Fig. 53. Port *d* is made small so as to restrict the flow of air into and out of chamber *A* sufficiently to cause chamber *A* pressure to charge at about the same rate for different lengths of train. This is necessary in order to make the signal valve operate the same on both short and long trains. A given reduction in signal-pipe pressure can be made much more quickly on a short train than on a long one, so that if port *d* were not restricted, chamber *A* pressure would charge much faster on a short train than on a long one. With port *d* of its present size, however, chamber *A* pressure charges at nearly the same rate for long and short trains, so that the signal valve operates about the same on trains of different length.

104. Operation of Valve.—When the signal pipe is being charged, air enters the signal valve at *X*, and, passing through the small port *d*, charges chamber *A*. It also passes through the passage *c* and feeds up slowly past the stem *10* into chamber *B*, charging this to the same pressure as chamber *A*. The pressures in chambers *A* and *B* and the signal pipe are equal when the pipe is fully charged.

When the signal cord is pulled and a reduction is made in the signal-pipe pressure, it causes a reduction of pressure in the signal valve also; but, since the stem *10* makes a rather snug fit, the pressure in chamber *A* above the diaphragm reduces faster than the pressure in chamber *B*; consequently, the diaphragm is forced upwards and raises the stem *10*, thus opening the port in valve seat *7*. The stem *10* is lifted until the groove *f* is above the bushing *9*, when the air in chamber *B* escapes quickly through the groove *f*, the milled spaces in the stem *10*, and the passage *e*, out to *Y* and the whistle, causing the latter to give a blast. Air also escapes from chamber *A* to the whistle, through the passages *c* and *e*,

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but is restricted in its passage from the train signal pipe into *A* by the small port *d*.

As air escapes from chamber *B* to the whistle, the pressures above and below the diaphragm quickly equalize. The diaphragm and its stem *10* will then move down, thus closing the passage *e* and thereby stopping the flow of air through *e* and preventing the blast of the whistle.

The same reduction of pressure that operates the signal valve also opens the reducing valve, allowing air from the main reservoir to flow into the signal pipe and raise the pressure in it. This increase of pressure, following the closing of the car discharge valve, and immediately after the reduction of pressure in the signal valve, increases the pressure in chamber *A* faster than in chamber *B*, thus holding the diaphragm down and keeping the valve leading to passage *e* closed.

SIGNALING

105. In **transmitting signals** by means of the air-signaling system, certain precautions must be observed in order to obtain good results. For each blast of the whistle, the car discharge valve should be held wide open just long enough to reduce the pressure in the signal pipe clear up to the signal valve on the locomotive, when it should be closed. It should then be allowed to remain closed until the pressure has equalized throughout the system, before it is again opened to transmit another signal. If the discharge valve is opened a second and, possibly, a third time before the whistle has ceased to blow due to the first reduction, the whistle will give one long blast instead of two or three short ones, as intended. If it is opened a second time before the pressure has fully equalized in the signal pipe, the whistle will give a blast after each discharge, but the last blast will be weak on account of the pressure being less than 40 pounds. If the discharge valve is not held wide open when giving a signal, the reducing valve may feed air into the signal pipe as fast as it escapes from the car discharge valve and the whistle will not give a blast.

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In transmitting signals, the best results will be obtained if the car discharge valve is allowed to remain closed from 2 to 3 seconds between blasts, depending on the length of the train. In other words, for each blast, pull the signal cord straight downwards and hold the discharge valve wide open for 1 second; then allow from 2 to 3 seconds for the pressure to equalize throughout the signal pipe before it is again opened for another blast. As it takes a longer or heavier discharge from the signal pipe from the rear car of a long train than from the front car, it therefore takes longer for the signal-pipe pressure to equalize and a longer interval between the blasts is necessary to get perfect signals.

DEFECTS IN THE SIGNALING SYSTEM

106. Although there are but comparatively few parts in the air-signaling system, it requires good judgment to locate defects that cause incorrect signals to be given. Also, it should be borne in mind that it is not so much the amount of the reduction as the rapidity with which the reduction is made that causes the whistle to blow.

107. Signal Pipe Fails to Charge.—If it is found that no air passes into the signal pipe, first see whether the cocks on each side of the hose between the locomotive and train have been opened. If so, the opening through the choke fitting *12*, or the strainers *7*, in the B-2 strainer and check-valve, Fig. 50, may be stopped up with oil and dirt, or the lining in the hose may be loose and blocking the passage; or, if the weather is cold, the signal pipe on the locomotive may be stopped up with ice, or the C-6 reducing valve may be frozen up.

108. No Exhaust From Discharge Valve.—If, when the signal pipe is properly charged, no exhaust occurs at the discharge valve when the signal cord is pulled, the trouble may be due to the cut-out cock being turned so as to cut out the discharge valve; or, it may be due to a loose valve seat in the discharge valve.

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109. Whistle Fails to Blow.—If an exhaust occurs at the discharge valve when the signal cord is pulled, but the signal whistle fails to give a blast, the strainer in the T, where the branch pipe connects with the signal pipe, is likely stopped up. In this case, the exhaust may sound all right, since there is considerable air in the branch pipe between the strainer and the discharge valve, but the air in the main pipe cannot get past the strainer fast enough to make a sufficiently quick reduction to operate the signal valve. If the trouble is not in the strainer, it may be: that the cut-out cock in the whistle pipe is closed; port *d*, Fig. 53, of the signal valve is stopped up, in which case no air can enter the valve to charge it; stem *10* of signal valve has worn sufficiently loose in bushing *9* to allow the pressure in chamber *B* to reduce about as fast as that in chamber *A*; the signal-valve diaphragm is bagged or, possibly, cracked; the bell of the signal whistle is imperfectly adjusted or its bowl is full of dirt; the whistle is so situated that wind blowing across the bowl prevents it from sounding; or there may be dirt in the port of bushing *7*, Fig. 53.

If poor rubber is used in the diaphragm, or if oil gets on it, the rubber will, in time, stretch and bag. In that event, when a signal-pipe reduction is made, the diaphragm will respond to it without raising the stem *10* from its seat in bushing *7*, and no blast will result. An overheated air compressor also tends greatly to heat the rubber and buckle or distort the diaphragm. In some cases, the diaphragm cracks, causing chambers *A* and *B* to become directly connected, in which case it is impossible to produce the difference in pressure on the two faces of the diaphragm necessary to operate the signal valve.

110. Whistle Gives One Long Blast.—If, in transmitting a signal, the whistle simply gives one long blast, the trouble may be due either to the reductions being made too close together, or to the diaphragm stem *10*, Fig. 53, of the signal valve working stiffly in the bushing *9*, in which event the passage at *e* would remain open until a sufficient differ-

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ence of pressure existed in chambers *A* and *B* to force the stem *10* to its seat.

111. Whistle Gives Weak Blast.—Sometimes the whistle gives only a weak blast when the cord is pulled. This may be due to the regulating spring of the reducing valve being too weak, so that there is less than 40 pounds of pressure in the signal pipe; the whistle may be full of dirt or may be improperly adjusted; or the passage through the bushing *7* in the signal valve, Fig. 53, may be partly stopped up with oil and dirt.

112. Signal Valve Leaks.—If, in the signal valve, Fig. 53, the valve formed by the end of the stem *10* leaks, or is held from its seat on bushing *7* by dirt, there will be a constant blow at the whistle.

113. Leaky Car Discharge Valve.—A leaky car discharge valve, due either to dirt on the seat of the valve, or to a defective valve seat, is a common source of trouble. If dirt on the valve seat is the cause of the leak, opening and closing the valve will blow the dirt off. As a rule this leak will be supplied by the reducing valve without causing a blast of the whistle. If the leak is such as to sound the whistle, and the valve cannot be replaced or repaired on the road, cut the valve out of service by closing the cut-out cock in the branch from the signal pipe.

114. Signal-Valve Stem Too Tight.—The accuracy with which signals can be transmitted depends to a considerable extent on the fit of the stem *10*, Fig. 53, in the bushing *9*. If it makes too tight a fit, the whistle will give one long blast instead of the usual short ones, as already explained. Also, signal-pipe leakage is liable to operate the signal valve and cause the whistle to sound a blast, and the signal valve will not respond to a short, light reduction.

115. Whistle Blows on Short Train but Not From the Rear End of Long Train.—If the fit of the stem *10*, Fig. 53, is too loose in the bushing *9* or the diaphragm *12* is

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baggy, the signal valve may not be affected by leaks; neither will it respond to a light, quick reduction in signal-pipe pressure. Also, when the train is short, the signal valve will respond to a reduction made on any of the cars in the train; but on a long train, the volume of air in the signal pipe is so much larger that a reduction through the car discharge valve on one of the rear cars may not produce a reduction sufficiently rapid at the signal valve to operate that valve, and the whistle will not sound.

116. Whistle Gives Two or More Blasts Instead of One.—If the stem *10*, Fig. 53, of the signal valve fits too loosely in bushing *9* and the train is short, the whistle, when the cord is pulled, is liable to give two or three blasts instead of one. This is caused in the following manner: As the cord is pulled, a reduction is made in the signal valve above the diaphragm, which causes the diaphragm to be raised, thus allowing air to escape from chamber *B* to the whistle, causing it to give a blast. The pressures in chambers *A* and *B* immediately equalize, causing the stem valve to close and stop the whistle. Then, as the reduction in the signal pipe continues, another difference in pressure forms between chambers *A* and *B*, causing the stem valve to be again opened and sounding another blast. In this way, two or more blasts may occur when but one reduction is made. When the stem fits properly, the pressure in the chamber above the diaphragm increases much faster than that in the chamber below it; hence, the diaphragm is held down and a second blast does not occur. In case the signal whistle gives two blasts when the cord is pulled, it can be remedied by lowering the stem *10* in the bushing *9*. The length of fit of the stem in its bushing should never be less than $\frac{1}{32}$ inch, nor more than $\frac{1}{16}$ inch, measuring from the top of groove *f* to the top of bushing *9*.

117. Whistle Blows Without Apparent Cause. A whistle will blow without apparent cause while the locomotive is running along if there is a leak in the signal pipe. The leak reduces the pressure in chamber *A* of the signal

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valve just a little below that in chamber *B*, so that a very slight jar of the locomotive will sometimes cause the diaphragm to rise and open stem valve *10*, thus causing a blast of the whistle.

TERMINAL TEST OF AIR-SIGNAL APPARATUS

118. In making up a train, the air-signal hose should be connected up at the same time the air-brake hose is, and all the signal-pipe cocks should be opened except the front and rear cocks on the train. These should be closed, and the signal hose hung up properly. All signal-whistle and car-discharge-valve cut-out cocks should also be open. While looking over the train for leaks, the signal hose and couplings and also the car discharge valves should be inspected to see whether they are in good condition. If a discharge valve is found to be leaking, jerk it open a few times; if this does not remedy the leak, the valve needs a new gasket. If a discharge valve is found defective while on the road, it should be cut out by closing the cut-out cock in the branch pipe; the conductor should be notified and he should report the same for repairs at the end of the run. In testing the signal system, signals should be transmitted from the rear car, from a car in the center, and from the car next to the locomotive. It is advisable to transmit signals from each car in the train in order to determine whether the car discharge valves are working properly.

119. Testing Device.—A device for testing the signal apparatus consists of a signal-hose coupler fitted with an air gauge and a small petcock having a $\frac{1}{8}$-inch hole in it. When this device is coupled to the signal hose and the signal-pipe stop-cock is opened, the signal-pipe pressure will be indicated by the air gauge, while, by means of the petcock, a reduction of any amount of duration may be made in the signal-pipe pressure.

120. Operation of the Testing Device.—The testing device may be used to determine the condition of the B-2 strainer and check-valve as follows: First connect the

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device into the signal pipe and charge the latter to standard pressure; then open the petcock wide, make a 10-pound reduction, and note the time required to raise the pressure to standard again. If the pressure rises slowly, and if the reducing valve is in good order, the passage through the choke fitting *12* or the strainer *7*, Fig. 50, is probably reduced by gum and dirt, and the device should be thoroughly cleaned.

If the gauge indicates a pressure of more than 45 pounds, the reducing valve is not properly adjusted.

To test the signal valve, make a slow, gradual reduction of about the same magnitude as the leaks in the signal pipe would amount to; then gradually increase the rate of discharge until the signal whistle sounds. If the whistle blows when a slow gradual reduction is being made, it indicates that the stem *10*, Fig. 53, does not fit loose enough in the bushing *9*, and that the pressure on the under side of the diaphragm cannot escape as the pressure above is reduced. The consequence is that the pressure in chamber *B* raises the diaphragm as soon as a sufficient difference of pressure is established between the chambers on either side of the diaphragm, and air discharges into the whistle, causing it to sound. If the whistle does not blow when a slow, gradual reduction is made, the indications are that the stem *10* fits too loosely in the bushing *9* or that the diaphragm is bagged. If the stem is too tight in bushing *9*, the signal valve will not close promptly and the blast will be drawn out longer than it should.

This testing device should be used as frequently as convenient so as to keep the apparatus in good condition. The test should be made before the locomotive leaves the roundhouse, so that all necessary repairs can be made before the locomotive is coupled to the train.

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SIGNAL SYSTEMS

INTRODUCTION

DEVELOPMENT

1. The introduction of the modern block-signal systems on large railroads has greatly increased the efficiency and safety of train movements. By dividing the tracks into certain lengths, called *blocks*, and installing certain safety devices, one train cannot approach another too closely without passing a warning signal.

On some of the early railroads where there was only one train running between two points, neither train orders nor a system of train spacing was required. With the development of the railroads and the corresponding increase of trains and train movements on the same track, it became necessary to arrange for meeting points of the trains; to install sidings for the passing of the trains; to protect trains moving in the same direction by a warning signal, in case the trains should come nearer to each other than a certain predetermined space; to protect trains moving in opposite directions by blocking; and also to provide a train-order system for the purpose of changing meeting points and for any other contingency.

2. In England, long before the telegraph was invented, signaling between stations was effected by means of a large ball that was raised or lowered on a high mast. One of these signaling devices was located at each station and was operated by an attendant, whose duty was to watch the

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signals at adjacent stations. Thus, for example, when a train left station No. 1, the ball would be raised to the top of the mast. When the train left station No. 2, the ball at that place would be raised to the highest position and the ball of station No. 1 would be lowered to half mast. When the train left station No. 3, the ball at that place would be raised to the highest position, the ball at station No. 2 would be lowered to half mast, and the ball at station No. 1 would be lowered to the ground. In this manner, the attendants at the stations were informed regarding the location of the trains. This system, however, was not a very reliable one.

3. With the advent of the telegraph into railroad work, the telegraph operators at the stations notified one another regarding the location and movements of the trains. In this way, the operators were enabled to place the signals at their stations to the *stop* or the *proceed* position, as desired. In case of heavy traffic, the distance between telegraph stations was decreased so that trains might follow each other more closely. This system is still in use on many roads, and although it has advantages over the visual method of communication, there still remained the necessity of a check that would make it impossible for an operator to permit a train to enter a block before ascertaining whether or not the block was clear.

The **lock-and-block system** contained an additional safety feature, in that it was impossible for a clear signal to be set, except by the simultaneous cooperation of the operators at both ends of the block. In this system, the signal was normally locked in the stop position, and communication between stations was maintained by telegraph, by telephone, or by code bells.

The **controlled lock-and-block system** was the first one to include the track rails as a part of the signal circuit. With this system it was impossible for the proceed signal to be set while a train was in the block.

4. In all the systems just outlined, the cooperation of one or more attendants was required to display the signals.

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As traffic on the roads increased with but slight increase of trackage, it became necessary to devise signal systems that would operate automatically and thus relieve the attendants of the task of setting the signals and at the same time increase the safety of train movements.

The operation of the signals of the **automatic block-signal system** is entirely controlled by the trains using the track to which the system is applied. A proceed signal will be displayed to an approaching train, at the entrance of a block, provided that no other train is in the block or that it contains no open switch nor broken rail. The signal will move to the stop position by gravity as soon as the first pair of wheels of a train passes the entrance of the block, and the signal will remain at this position until the last pair of wheels of the train has passed out of the block at the distant end.

There have been extensive developments in electric-railway systems for interurban service. Signal systems for this class of work usually differ somewhat from the systems used on steam roads. This Section will treat of the signal systems for electric roads.

DEFINITIONS AND CLASSIFICATION

5. A **block** is a length of track of defined limits, train movements over which are controlled by signals.

A **block signal** is a signal, fixed as regards to location, that controls the use of a block.

A **block system** is any method of keeping a fixed minimum interval of space between two trains moving in the same direction on the same track, and of giving proceed or stop indications to trains moving in opposite directions on the same track.

An **absolute block system** is one that allows only one train in a block at one time.

A **permissive block system** is one that allows any desired number of trains to follow each other into a block, the trains following the first train being warned that the block is occupied.

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A **telegraph block system** is one in which the orders relating to train movements are transmitted by telegraph to the signal operators and the signals for the approaching train are manually operated.

A **controlled manual block system** is one in which the signals are operated manually and the system is so arranged as to require the cooperation of the signalmen at both ends of the block in order to display the clear or the proceed signal.

An **automatic block-signal system** is one in which the signals are automatically operated by electric currents, by air pressure, or by other means. These operations are controlled by train movements or by conditions affecting the use of a block.

6. The **interlocking plant** is placed under the general classification of block systems. This plant is an arrangement of switches, locks, and signal appliances so interconnected that the movements of the parts must follow each other in a predetermined order. Such plants are installed near points where roads cross each other or where routes converge, as at the entrances to yards or terminals. The interlocking plant is also used for setting up proper train routes and for conveying information to train operators.

7. An **interlocking signal** is the fixed signal of an interlocking plant.

A **manual signal** is one that is operated by hand.

A **semiautomatic signal** is one that automatically moves to the stop or the proceed position, but must afterwards be reset into its normal position by hand.

An **all-automatic,** or **automatic, signal** is one that is entirely operated by power. It is controlled by train movements and by the condition of the track and track circuits of the block.

A **home signal,** shown in Fig. 1, is generally used to give the absolute stop or the proceed indication to a train desiring to enter a block. It is a fixed signal at the entrance of the block.

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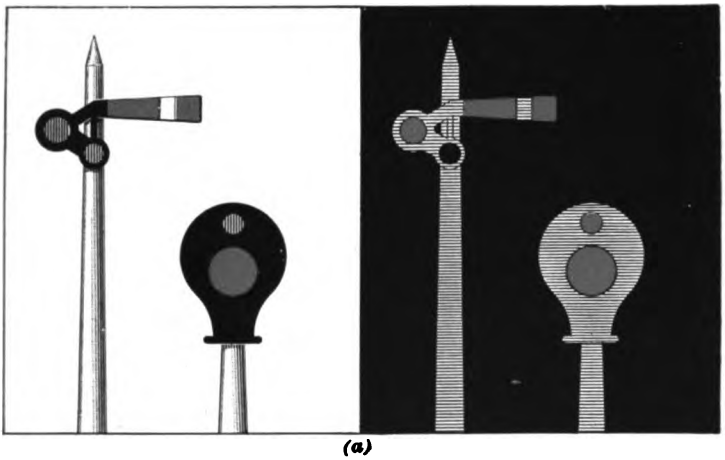
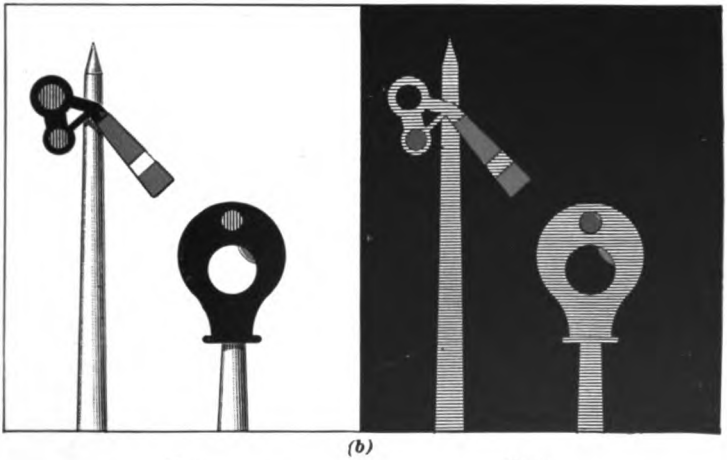


(a)

Day Night

STOP SIGNAL—Indication: Stop



(b)

Day Night

CLEAR SIGNAL—Indication: Proceed

FIG. 1

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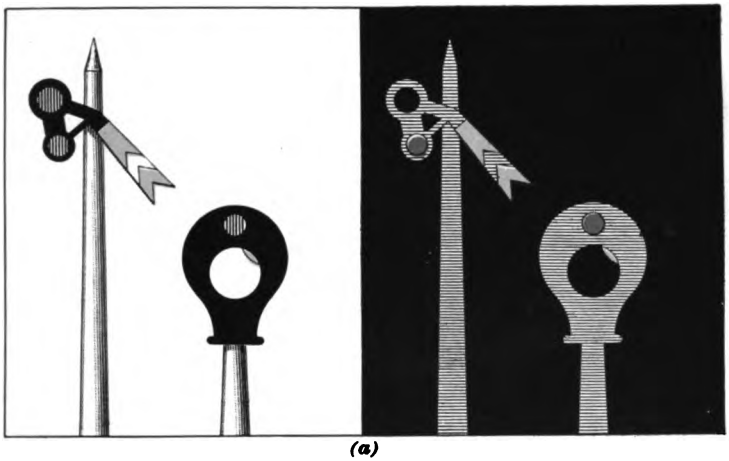
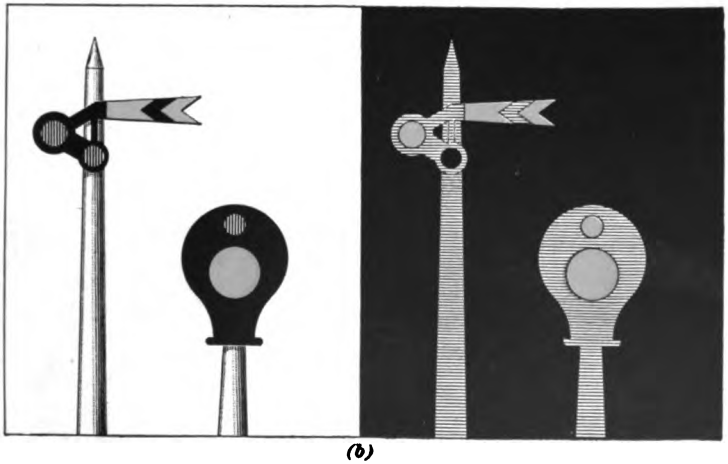


(a)

Day Night

CLEAR SIGNAL—Indication: Proceed



(b)

Day Night

CAUTION SIGNAL—Indication: Proceed with Caution to Home Signal

FIG. 2

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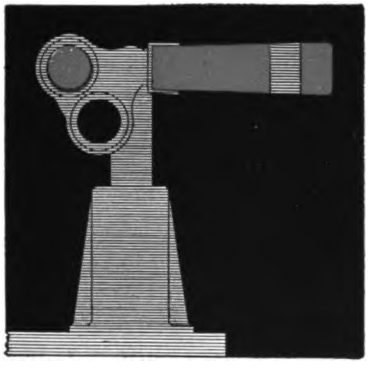
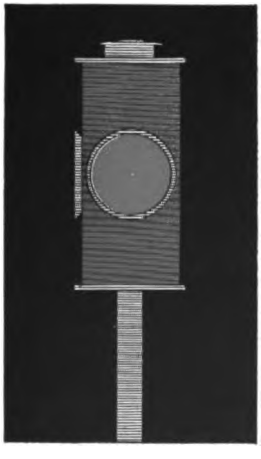


Night
STOP SIGNAL—Indication: Stop

FIG. 3



Night
STOP SIGNAL—Indication: Stop

FIG. 4

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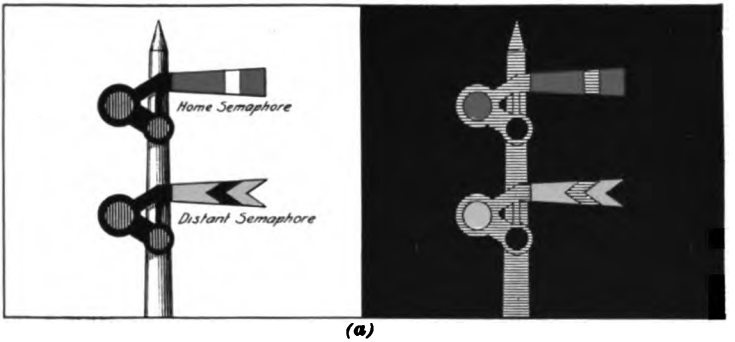
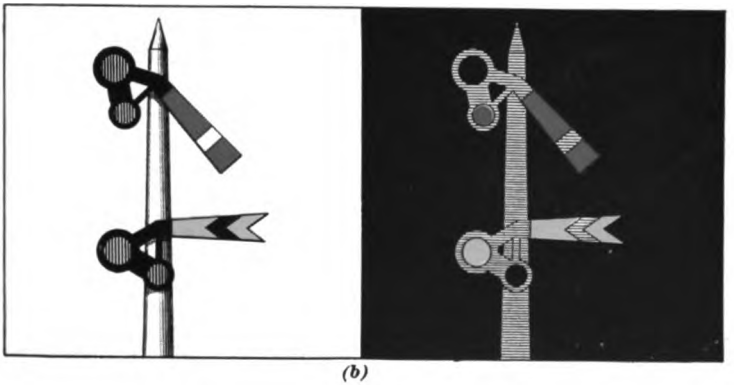


(a)

Day Night

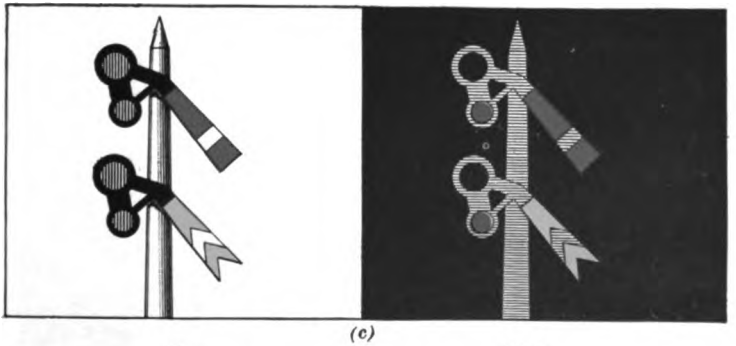
STOP SIGNAL—Indication: Stop



(b)

Day Night

CAUTION SIGNAL—Indication: Block is Clear, Approach Next Home Block Signal With Caution



(c)

Day Night

CLEAR SIGNAL—Indication: Two Blocks Ahead Are Clear

FIG. 5

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A **distant signal,** shown in Fig. 2, is used in conjunction with a home signal to govern the approach of the train to the home signal; that is, it indicates to the train operator the condition in which he may expect to find the home signal.

A **dwarf signal,** shown in Fig. 3, is a low, fixed signal of distinctive character, being generally of the semaphore pattern.

A **pot signal,** shown in Fig. 4, is a revolving-disk signal generally used for a switch indicator. It is sometimes used as a substitute for a dwarf signal. Each side of the box and its corresponding disk has a distinctive color.

Semaphore-signal indications are displayed in the daytime by the position of an arm that moves in a plane at right angles to the track, and at night they are displayed by colored lights. (See Figs. 1 and 2.)

Other types of signals are generally *light signals*, the presence or absence of a light or of colored lights conveying the desired information.

LANGUAGE OF SIGNALS

8. The presence or the absence of a train in a block is indicated by the signal or signals governing that block.

The home semaphore, or position signal, indicates danger or stop when the blade, or arm, is at right angles to the signal pole.

The clear, or proceed, indication is given when the blade is 60° or 90° from the horizontal.

The indications are displayed at night by a red light for danger, and generally a green or a white light for clear.

The same positions of the blades displayed by distant signals regulate the approach of trains to the home signal, the distant signal being a preliminary signal. Different roads use different colors, but in some cases where a yellow light is used at night on the distant signal for stop and caution indications, a green light is used for the clear indication, as shown in Fig. 5.

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Where no semaphore signals are used, all indications being given by lights placed behind colored lenses, red and white lights are generally used. These lights convey the same information as the lights of the semaphore type of signals.

9. The automatic signal may sometimes become deranged or it may assume the stop position from causes other than a train in the block. In order that traffic may not be suspended in such cases for an unnecessary length of time, the usual instructions to train runners are to wait a few minutes and then proceed with caution through the block, expecting to find that the block is already occupied by another train, or that it contains a misplaced switch or a broken rail.

On a single-track road, it is necessary, in case of disorder to the signal apparatus, to send a flagman ahead to protect the train passing through the block from a train that may be coming in an opposite direction.

The many interurban roads have only been made possible by keeping the cost of the equipment and roadbed to a minimum, which necessarily limited the roadbed to only a single track.

The numerous difficulties that arise in the proper signaling of a single-track road are due to the fact that it is necessary to protect trains that are moving not only in the same direction but also in opposite directions on the same track.

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DESCRIPTIONS OF SIGNAL SYSTEMS

MANUALLY OPERATED LIGHT SIGNAL

10. In Figs. 6 and 7 are shown the signal-wire connections of a simple system of **manually operated light signals** that is used extensively on single-track roads running comparatively few cars.

A signal box of the type shown in Fig. 7 is installed at each end of a block. A red light at either signal station indicates that a car is in the block, and no other car is per-

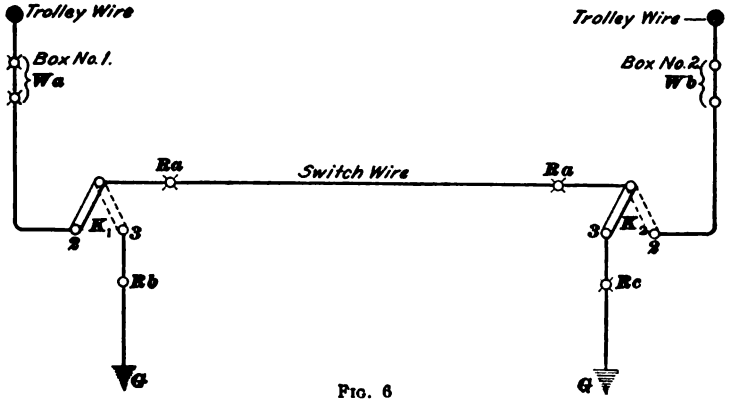

FIG. 6

mitted to pass into this block until the signal shows clear, which is indicated by the red lights being out. If the block is clear, a car may pass into it. The motorman or the conductor then throws the switch at the signal box, thus lighting the red lamps at both ends of the block. These lights signify that the block is occupied, and warn all approaching or following cars to keep out. On leaving the block at the opposite end, the motorman throws the switch at that signal box, thus putting out the lamps and giving the clear indication at both ends of the block.

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11. In Fig. 6, which illustrates the signal circuits of this system, are shown two simple two-way switches K_1 and K_2 that are manipulated by the motorman or the conductor on entering and leaving a block. The two switch blades are connected together by the switch wire, as shown. Two 16-candlepower incandescent lamps *Ra* having red globes are connected in the switch-wire circuit. Each switch has a trolley connection that includes two white lamps *Wa*

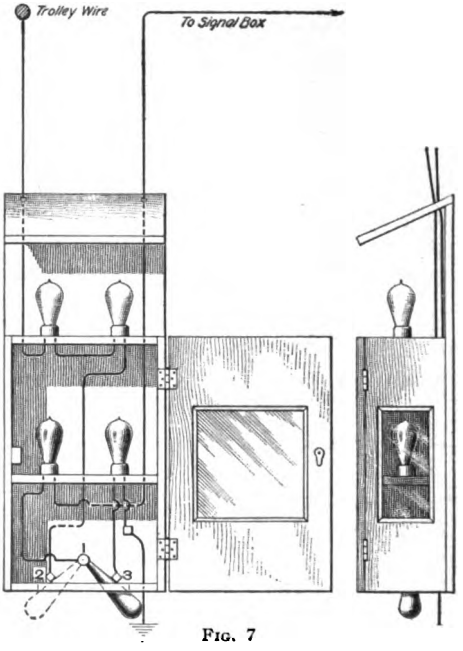

FIG. 7

or *Wb* and a ground connection *3* that includes a red lamp *Rb* or *Rc*.

When the two switch blades are in the full-line position, the two white lamps *Wa* and the single red lamp *Ra* light in signal box No. *1* at, say, the west end of the stretch of single track; only the two red lamps *Ra* and *Rc* light in box No. *2* at the east end. If the two switch blades occupy the positions shown by dotted lines, current from the trolley connection at box No. *2* takes the path, trolley–*Wb*–*2*–K_2–*Ra*–*Ra*–K_1–*3*–

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Rb–G, and lights the two white lamps *Wb* and the red lamp *Ra* in box No. *2*, and red lamps *Ra* and *Rb* in box No. *1*.

No matter what the position of the two switch blades may be, if the lights are extinguished and their extinguishment is not due to a fault, throwing either of the blades to the opposite side of the signal box will light a red lamp at both ends of the block, thus giving the danger signal. If the signal lamps are burning, throwing the switch at either end of the block—from its position when the lamps are burning to the opposite side of the box—will extinguish all the lamps and give the clear indication for the block. In Fig. 6, with full-line position of the switches, throwing either K_1 to *3* or K_2 to *2* will extinguish all the lamps.

12. The objections to an arrangement of this kind is that, being manual, it it not absolute, and a signal may be passed intentionally or unintentionally without being set; also, if one car follows another into a block and is so far behind the first car that it cannot be seen, the motorman of the first car on passing into the next block may clear the signal, thinking that his car is the only one that was in the block. A car entering the block and moving in the opposite direction to the direction of movement of the other two cars will meet the second car in the block. Where such a system is installed, it is, of course, necessary to cover such contingencies by the rules of the operating company. These rules state which car must return to the siding and give up the right of way to the other car.

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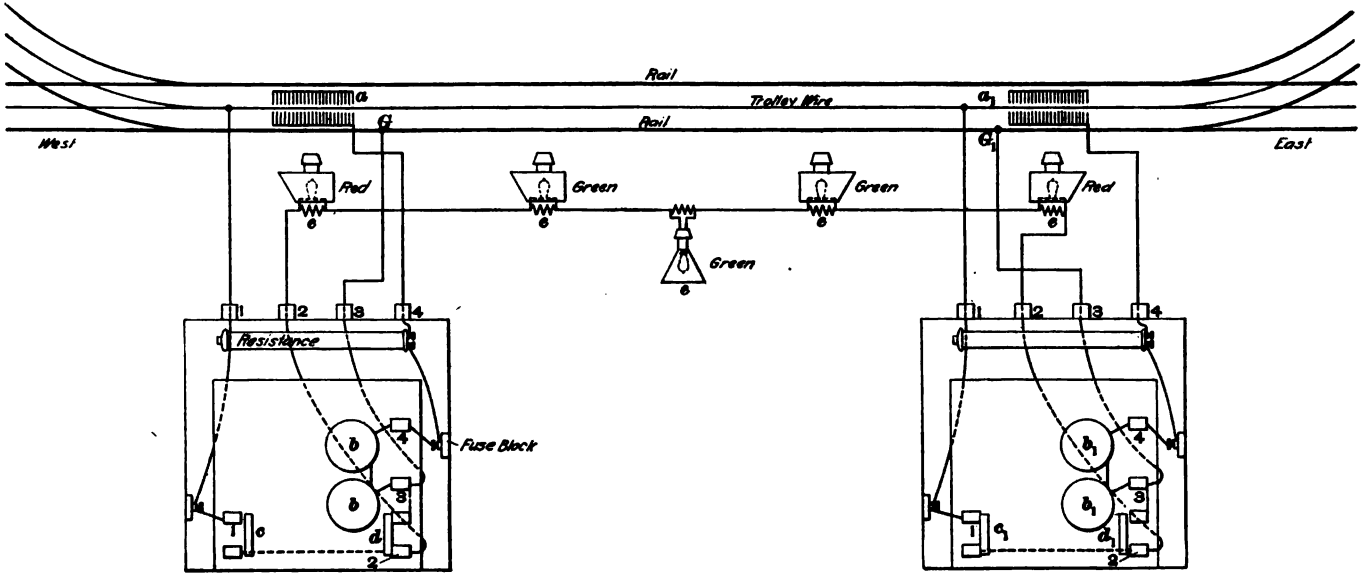

FIG. 8

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AUTOMATIC, SINGLE-WIRE BLOCK SYSTEM

13. Description of Apparatus.—In Fig. 8 is shown an **automatic, single-wire block system** that accomplishes the same results as the manually operated signal system just described. The switches in this system are operated by electromagnets instead of by hand.

At each end of a length of single track between sidings, in positions a, a_1, Fig. 8, a contact maker of the general form shown in Fig. 9 is installed. The contact springs on one side of the trolley wire, Figs. 8 and 9, are connected together, and may or may not be connected permanently to the trolley wire. The contact springs on the other side of the single-

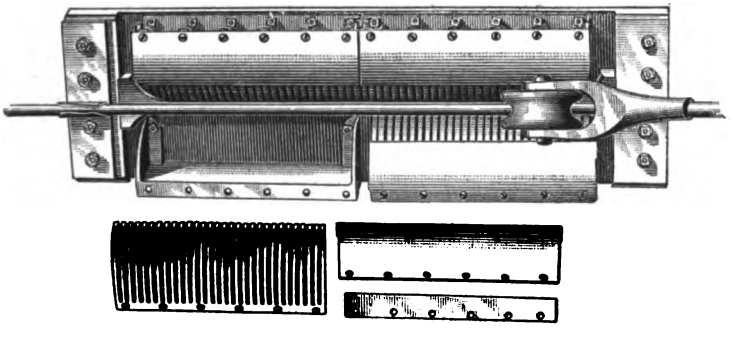

FIG. 9

wire contact maker are connected together, and are also connected to either magnet b or b_1, Fig. 8, and thence to the ground at G or G_1. Normally, the two sets of contacts, called *finger plates*, are not connected electrically.

A trolley wheel when passing the contact maker bears on the trolley wire and also on these two sets of contacts, and thus completes the circuit from the trolley wire through the magnet to the ground. The magnet a of the controller, Fig. 10, is energized, and its armature, in moving, turns the ratchet wheel b and the notched wheel c. The right-angled levers d and e are actuated by the movements of the notched wheel, and these levers, in turn, alternately

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open the switches f and g by bearing on extensions of the switch arms. The switches are normally held in a closed position by gravity. When one switch is open the other switch is closed. The little rollers connected to the levers d and e are held against the surface of the notched wheel by means of a spring h attached to the tops of the levers. The spring also prevents the notched wheel from being turned accidentally. In Fig. 8, the switches are shown at c, d, c_1, and d_1.

14. Operation.—In Fig. 8, it is assumed that a car is in the block and that it is moving toward the west. As

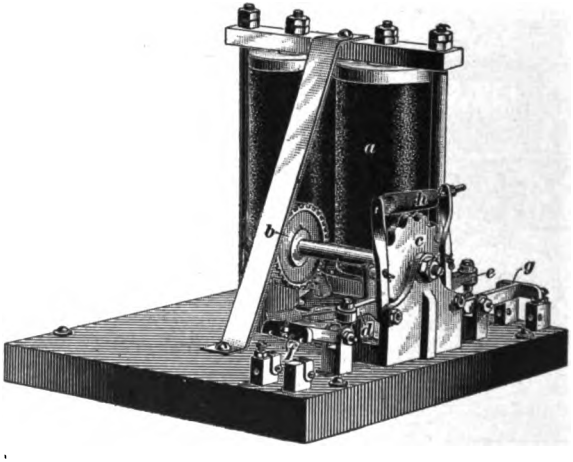

FIG. 10

switches c_1 and d are closed, current can flow from a_1 to G; this causes the signal lamps e in the block to burn, thus indicating danger. Each lamp is shunted by a resistance, so that if one burns out, current can still flow through the shunt and the other lamps. When the trolley wheel makes contact with finger plate a at the west end of the block, magnet b at that end becomes energized, causing switch c to close, and switch d to open. The ground connection of the signal lamps is thus cut out, and the lights are extinguished. The block is now clear.

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15. If a car now enters at the west end, the magnet b is again energized and the switches c and d are thrown into the positions indicated in Fig. 8, thus setting the danger signal. When this car passes out of the block at the east end, magnet b_1 is energized, switch d_1 is closed, and switch c_1 is opened, thus cutting out the trolley-wire connection of the signal lamps and extinguishing them. The block is now clear.

The lamps in the block enable the motorman of the car to tell whether or not the danger signal has been disregarded (shown by the lamps going out), but do not indicate the direction of movement of the offending car.

AUTOMATIC, PERMISSIVE TWO-WIRE BLOCK SYSTEM

16. Description of Apparatus.—In many instances, where both local and interurban cars run over the same short section of single track, or where conditions are such that the major portion of traffic is in one direction, it is advantageous to make use of a **permissive signaling system.** In such a system, a specific number of cars moving in the same direction is allowed to enter a block, and each car is protected by keeping the signals set until the last car has passed out.

17. The wiring diagram of a permissive signaling system is shown in Fig. 11. In this system, the contact maker is similar to the one shown in Fig. 9. The contact springs on one side of the trolley wire are connected together and form one finger plate, but those on the other side are divided into two finger plates that are insulated from each other.

The front and the rear of a controller for this system are shown in Figs. 12 and 13. The operation of this controller is, in general, similar to that of the one shown in Fig. 10. In Figs. 11 and 12 corresponding switches are lettered in a similar manner. An auxiliary controller is shown in Fig. 14, and the type of semaphore used is shown in Fig. 15.

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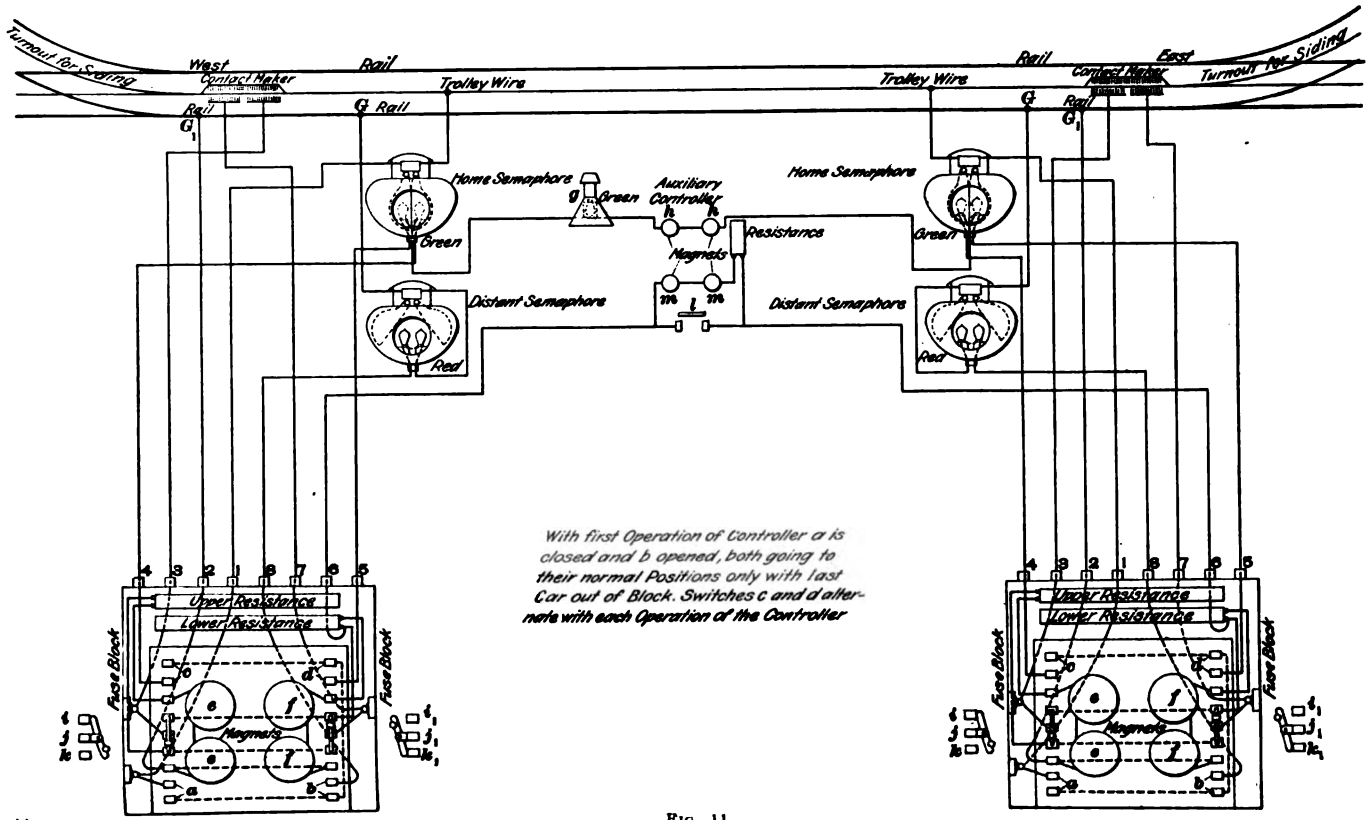

FIG. 11

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18. The signal circuit operating the lamps extends from one end of the block to the other and passes across

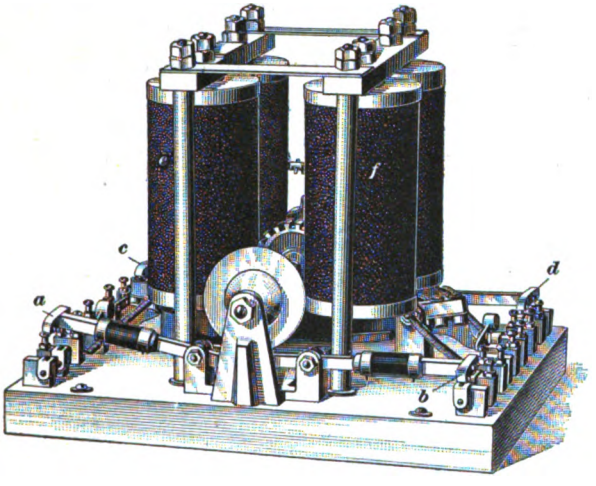

FIG. 12

the base of the controllers and through some of the switches *a*, *b*, *c*, and *d*, Fig. 11, without passing through the electro-

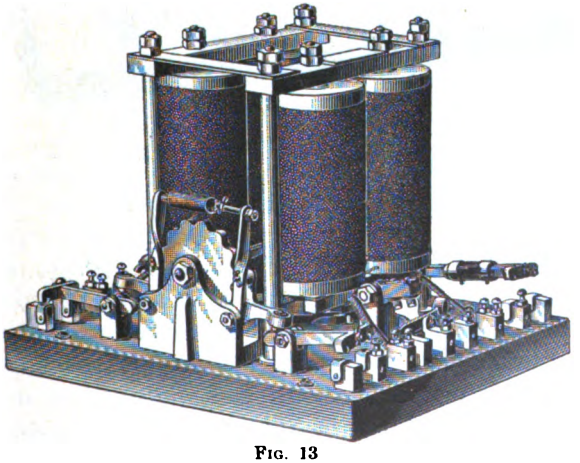

FIG. 13

magnets *e* or *f*. When the block is not occupied, the signal line is grounded at both controllers through switches *b* and

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wire *8*. Since the line is grounded at both ends, no current flows, and the signal lamps do not light. The manner in which the ground connections are made may be learned by tracing the following path: *G*, near the west end of the block–magnet for opening the shutters of the red lamps –two red lamps–*8*–*b*,closed when block is clear (*a* being open)–*d*,closed (*c* being open)–*5*–green lamp at the left–line lamp *g*–auxiliary controller magnet *h*–green lamp at the right–*5*–*d*,closed–*b*,closed–*8*–two red lamps–magnet for opening the shutters of the red lamps–*G*, at the east end of the block.

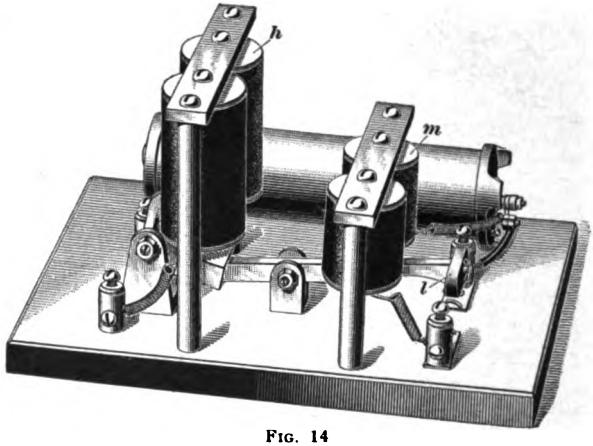

FIG. 14

It should be noted that the red danger signals are connected between the controllers and the ground. Which of the two green lamps at each station is lighted, depends on whether switch *c* or switch *d* is closed. These switches are actuated by the notched wheel on the controller, and while one is open the other is closed. The block-signal line is connected to the junction of the two green lamps.

Switch *a*, if closed (*b* open), and wire *1* at each station provide the signal line with two trolley connections, but no ground connection. With both controllers set to ground or to trolley, no current can flow, and consequently no caution or stop signals can be given. The signals can be set

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to danger only when one controller is operated to close switch *a*, thus providing a trolley connection, and when the ground connection of the other controller is left intact. Switches *a* and *b* are operated by the cam shown in Fig. 12 (also, see the note in Fig. 11).

19. The direction switches $i\,j\,k$ and $i_1\,j_1\,k_1$, Fig. 11, are closed by gravity and are normally in the positions shown. Switch $i\,j\,k$ is operated by a lug on the armature of magnet *e* and is thrown so that points *j* and *k* are connected, while switch $i_1\,j_1\,k_1$ is operated by a lug on the armature of magnet *f*, and is thrown so that points j_1 and i_1 are connected. When the magnets are deenergized, the switches fall by gravity and assume their normal positions.

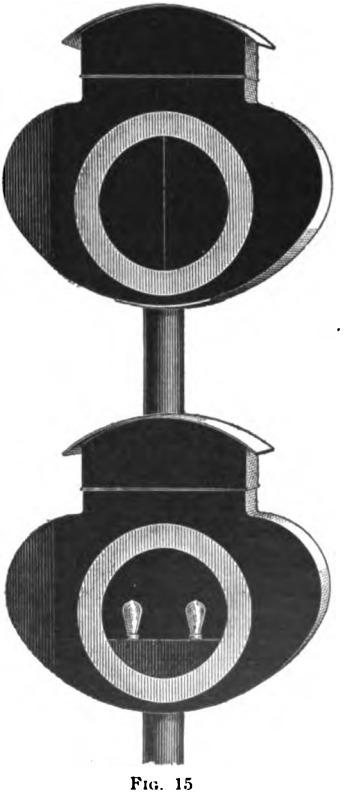

FIG. 15

20. Operation.—Referring to Fig. 11, assume that a car enters the block at the west end. Current flows from the trolley–first finger plate–7–fuse –j_1–k_1–*k*–upper resistance–magnet *e*–2–G_1. This operation sets the direction switch from points *i* and *j* to points *j* and *k*, closes switch *a*. and opens switch *b*. When the trolley has moved to the second finger plate, the current flows through 3–fuse–*j*–*k*–upper resistance–magnet *e*–2 –G_1. The magnet *e* is thus energized while the trolley is passing over the whole length of the contact maker, and the direction switch is maintained in position *j k* until the trolley leaves the contact maker. Additional cars entering the block in the same direction repeat the operation

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of the direction switch. Switch *a* remains closed, and as switches *c* and *d* alternately close and open at each operation, either one or the other of the two green lamps at the west end will light.

21. The closing of switch *a* provides a trolley connection. Current can flow from the trolley wire–magnet of the green lamps–*1*–*a*–*c*–*4*–green lamp at the right in the left-hand home semaphore–*g*–magnet *h* (thus closing switch *l* after the trolley wheel has left the contact maker, as will be explained later)–green lamp at the right in the right-hand home semaphore–*5*–*d*–*b*–*8*–two red lamps–magnet of red lamps–*G*. Thus, one of the green lamps *g* at the west end and one of the green lamps and the two red lamps at the east end are lighted. The magnets over these lamps operate to open the shutters. The danger signal is thus set for any car waiting at the east end of the block.

22. When there is only one car in the block and this car is passing out at the east end, the trolley first makes contact with the finger plate connected to wire *3* and current then flows from *3*–fuse–j–i–i_1–lower resistance–magnet f–*2*–G_1. Switch i_1 j_1 k_1 is thrown so that points j_1 and i_1 are bridged; thus, current from the other lower finger plate, when the trolley passes into contact with it, is allowed to flow through *7*–fuse–j_1–i_1–lower resistance–magnet f–*2*–G_1. Magnet f is energized during the passage of the wheel over the entire length of the contact maker.

Current can also flow from the junction near the lower resistance through *6*-switch *l*, closed–*6* at the west end of the block–lower resistance–magnet f–*2*–G_1. Magnet f closes switch *b* and opens *a*, thus cutting out the feed connection. The signal lamps are then extinguished and the block cleared. Current cannot flow from the junction of wire *6* and the lower resistance at the west controller, because the path, junction –i_1–i–j–fuse–*3*, is open at the contact maker. Cars entering the block at the east end and leaving at the west end cause similar operations of the controllers, except that the east controller is operated first.

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23. The auxiliary switch *l* will close when cars enter only at one end of the block and pass directly through it, but should cars enter at both ends—at one end contrary to the signals—and thus connect the signal line to the trolley at each end of the block, no current can flow through magnet *h*, and switch *l* will open. The signal lamps will be extinguished, as they are in series with magnet *h*. When the car that entered the block contrary to signals backs out, current from the contact maker at that end can only operate the near-by controller to make a ground connection again, and cannot operate the distant controller because of the open switch *l* in the circuit of wire *6*. The switch *l* cannot close while the trolley wheel is passing over the contact maker, as will be explained later. The switch will close, due to the signal-line current, after the car has backed completely out of the block. As the ground connection is again established, the signal lamps will glow, and the danger signal will be set against the car that has just backed out of the block.

When a car passes through the block without being interfered with by cars at the end which it approaches, the switch *l*, which is now closed, in connection with wire *6*, provides a path for the current from the contact maker. This current flows back to the distant controller and changes it from trolley to ground connection, thus extinguishing the lamps and clearing the block.

24. In case a red lamp burns out while a car is passing through a block, the signal-lamp circuit is opened because the red lamps are not shunted. Switch *l* opens, and a car moving in the opposite direction to that of the first car and entering the block, can throw the near-by controller to trolley connection, but it cannot throw the controller at the distant end to ground connection on account of the open switch *l*. The signal-line circuit thus has a trolley connection at each end, and the red lamps at the distant station and the green lamp at the near-by station will not light, thus indicating that there is some disorder in the signal system.

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If the red lamps were shunted by a resistance across both lamps and one of the lamps burned out, a car entering a vacant block would light a green permissive signal at its end of the block and be unprotected by red lamps at the distant end.

25. The function of magnet *m*, Figs. 11 and 14, in the auxiliary controller is to hold switch *l* open, against the tendency of magnets *h* to close it, as long as current is supplied from the contact maker. When the trolley wheel first makes contact with the finger plate of the contact maker, Fig. 11, current can flow from the first finger plate at, say, the west end–upper resistance–magnet *e*–lower terminal of magnet *e* across the base to the lower terminal of magnet *f*–magnet *f*–lower resistance–wire *6*–magnet *m*–resistance–*6*–lower resistance at east end–magnet *f*–lower terminal of magnet *f*–across the base to the lower terminal of magnet *e*–wire *2*, to the ground. Because of the large amount of resistance in the circuit, the current is so small that it cannot operate the main controllers; but since the armature of magnet *m* in the auxiliary controller is very near the magnet, switch *l* is held open until the trolley wheel has passed beyond the contact maker. The signal-line current, acting alone, then closes switch *l*.

26. Each car following the first car into the block energizes magnet *e*, Figs. 11 and 12, and causes the notched wheel to turn in the same direction of rotation and to bring about the alternate opening of switches *c* and *d*, which in turn light one or the other of the two green lamps. The device that closes switch *a* and opens switch *b* moves around as the notched wheel is rotated, and it cannot again be active in moving these switches until the same number of cars that entered at one end passes out at the other end of the block.

Each car in passing out of the block energizes magnet *f*, and this magnet turns the notched wheel in the opposite direction of rotation to that in which it was rotated by magnet *e*. When all the cars have passed out, the notched wheel is back in its original position, and switch *a* is opened and

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switch *b* closed. If all the cars do not pass out, the notched wheel will not turn back far enough to permit a change in the switch positions of *a* and *b*. Therefore, the red danger signal is exposed at the distant end of the block and one or the other of the green permissive lamps is displayed at the near-by end of the block until the last car does pass out. The block is then cleared for cars moving in either direction.

27. In Fig. 11, which illustrates the simpler method of permissive-signal installation, two contact makers are used. However, where spring track switches that cannot be operated by hand are used, it is preferable to install four contact makers. Two of these should be placed at the ends of the blocks, and one over each branch siding. The use of four contact makers will cause the signals to operate before a car passes the track switch. If this switch is once passed and the car cannot continue through the block, it will have to back around the turnout.

28. The mechanism of the controllers in this system should be designed so that they will not set permissive signals for too many cars moving in the same direction to enter the block, because all these cars must pass out of the block before the waiting car or cars at the other end can enter.

When limited to a few cars, this system, under certain operating conditions, possesses many advantages over the absolute block system.

TELEPHONE SEMAPHORE SIGNALS

29. On many of the interurban electric lines, the train despatcher depends entirely on the telephone for the proper control of the trains. Telephones are installed at certain points on the line so that in case any unforeseen derangement of traffic occurs, or other conditions arise that may necessitate changes of or additions to the original orders, the train crew can call up the despatcher, or starter, for instructions.

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Such conditions are also met on steam roads, but they are readily taken care of by means of telegraph lines and more or less closely located telegraph stations. On roads

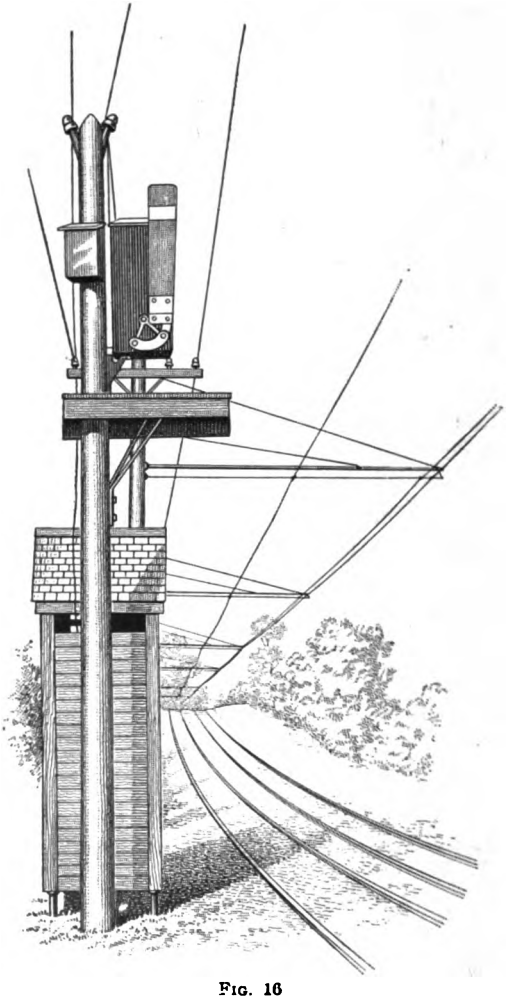

FIG. 16

that depend entirely on the telephone, instructions are issued to the train crews to call up the despatcher from certain points. Sometimes, the delay that necessarily follows is

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not warranted, as in many instances the despatcher has no other instructions for the crew than those originally given.

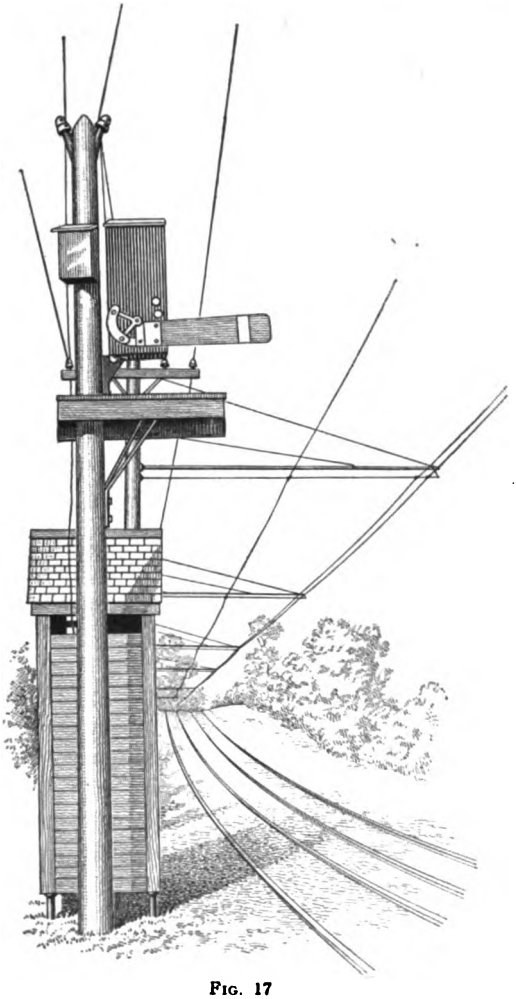

FIG. 17

30. The **selective signal system** used on many interurban electric lines permits the despatcher to communicate with any car crew at will. To summon a crew to

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the telephone, the despatcher sets such signal as he may desire at danger position. This signal is a semaphore having a blade about 4 feet long. At night, red lenses illuminated by signal lamps are used to display the danger signal. Fig. 16 shows the semaphore set at clear, and Fig. 17 shows it set at stop. The interior of a telephone booth is shown in Fig. 18. These booths are installed at all important meeting points on the road. Fig. 19 shows the desk at the despatcher's office that contains the mechanism necessary for the operation of the line signals.

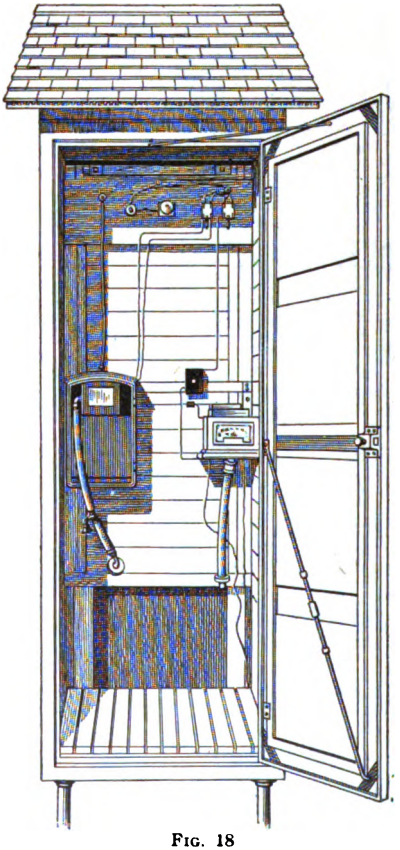

FIG. 18

31. The more important features of this signal system are illustrated in the simplified diagram shown in Fig. 20. In the desk at the despatcher's office are installed fifteen master pendulums. Each pendulum is of different length and has, therefore, different natural rates of vibration. At each of the fifteen signal stations connected to any one line wire running from the despatcher's office is installed a pendulum, the natural vibration of which is the same as one of the pendulums at the office.

A master pendulum when in operation opens and closes the main-line circuit by means of a switch actuated by the upper portion of the pendulum. Since the switch is closed once for every complete swing (to-and-fro motion) and at

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only a certain position of that swing, timed current impulses are set up in the line. All magnets actuating the line signal pendulums are in series on the line wire. The armatures of the signal magnets are periodically attracted toward the poles of the magnets, and projections of the armatures press against the pendulums and set them in motion.

32. The impulses just mentioned energize the signal magnets at all the stations and start vibrations in all the

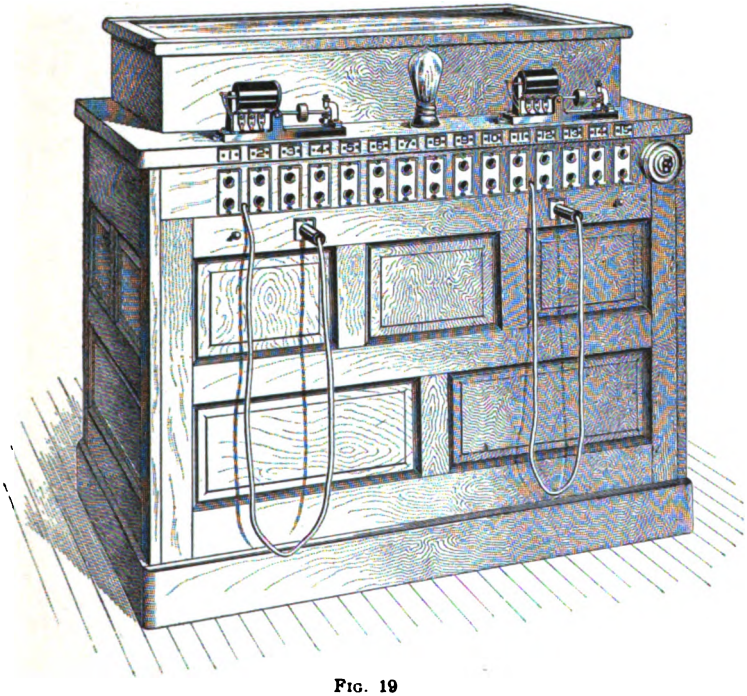

FIG. 19

signal pendulums. On only one signal, however, namely, the one whose pendulum is of such length that its natural vibration is synchronous with the vibration of the active master pendulum and the impulses that are being sent over the line, will the movements of the signal-magnet armatures be properly timed so as to be cumulative in effect and thus increase the amplitude of the swing of the pendulum until

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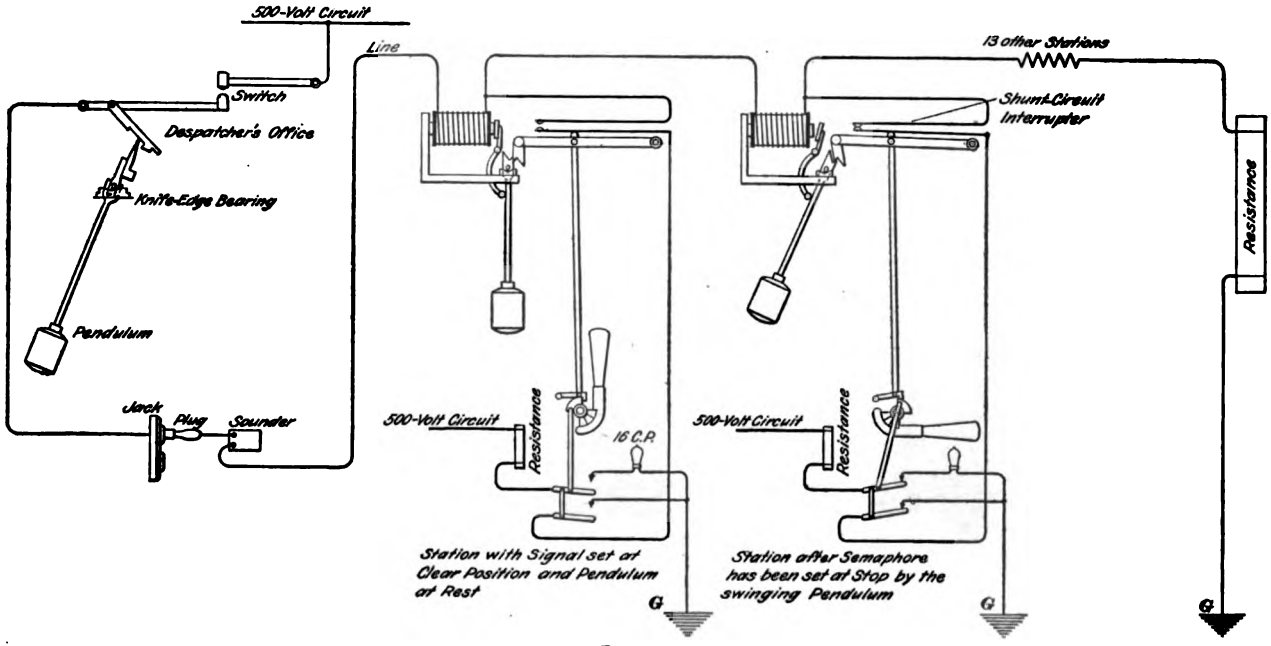

FIG. 20

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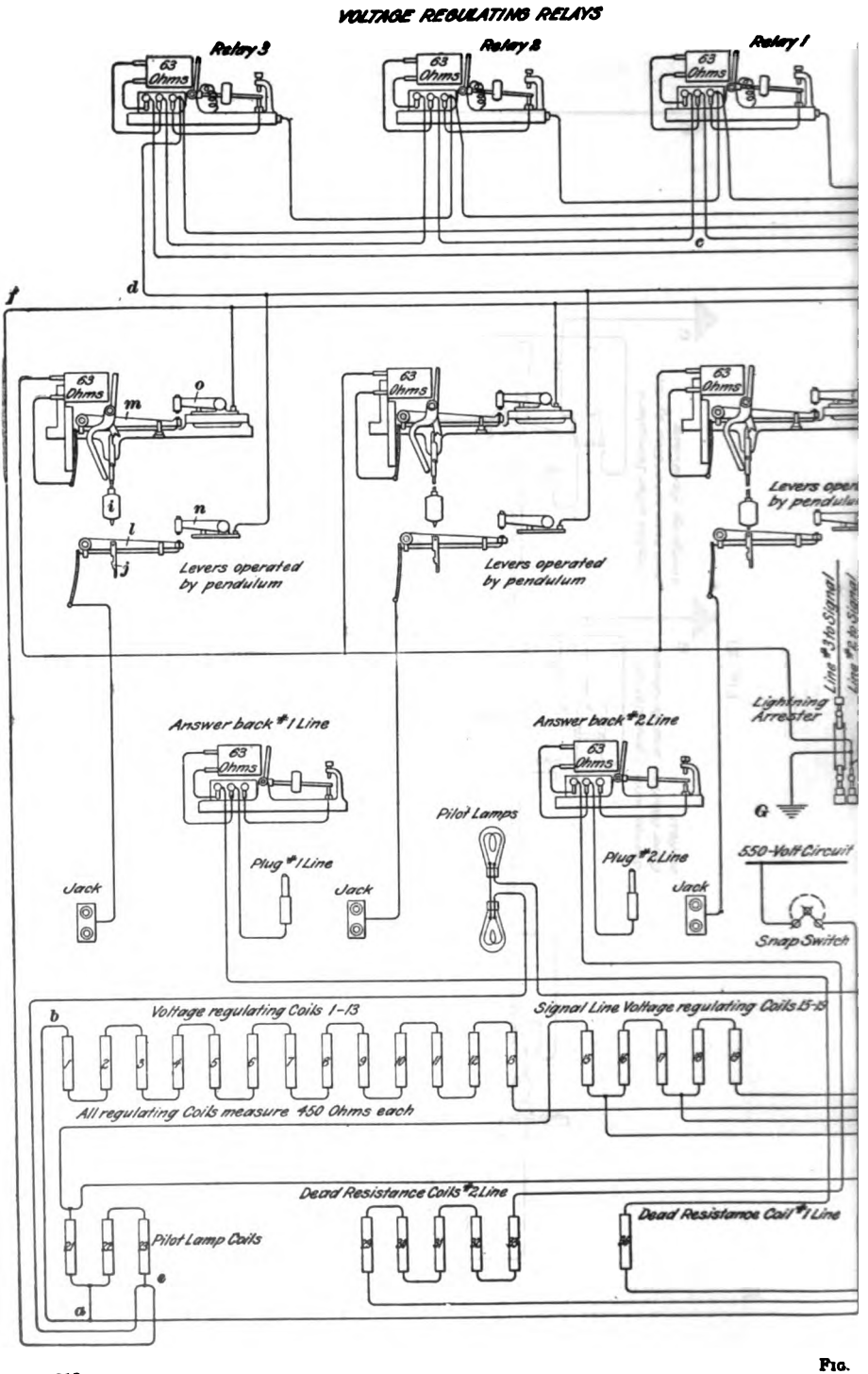

FIG.

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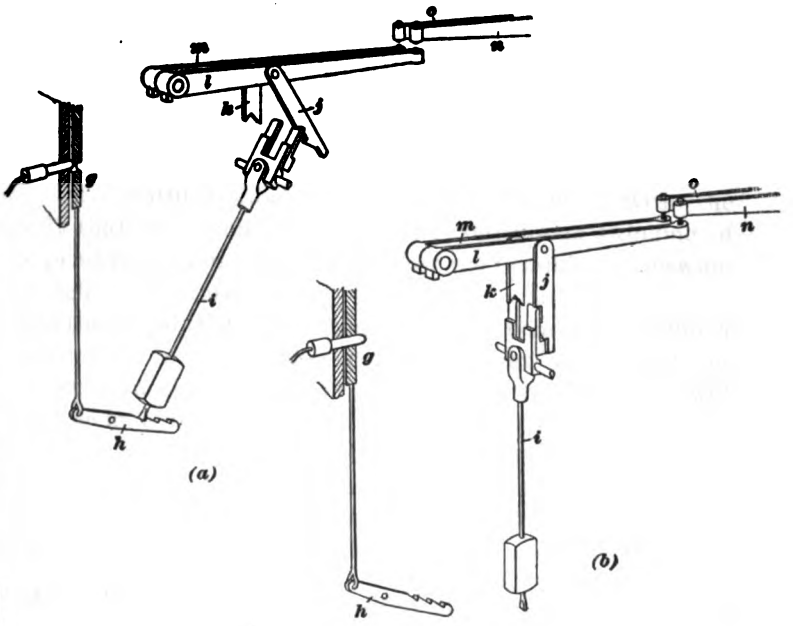

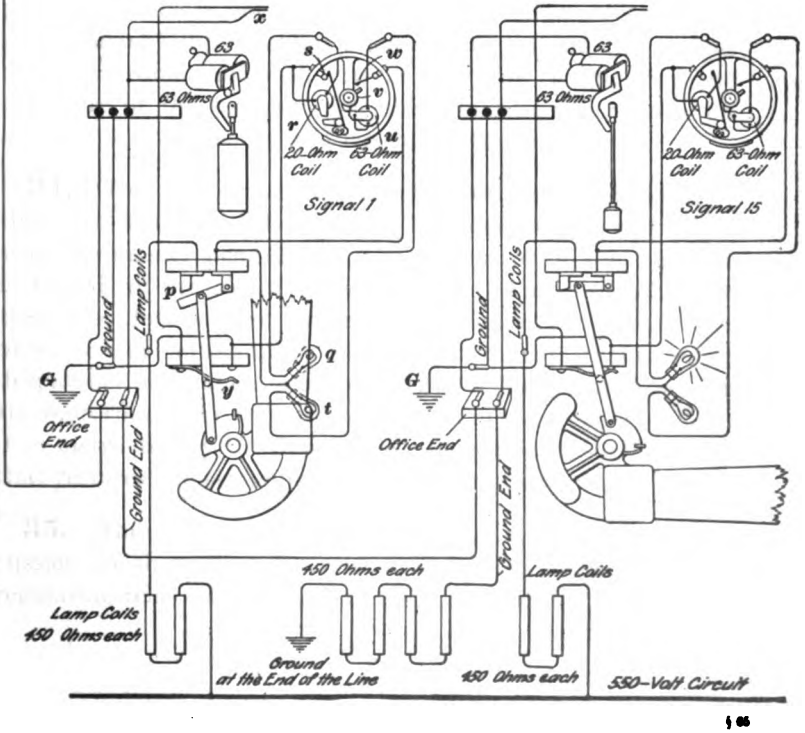

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it moves through a large arc. The signal magnets of the other signals will move their armatures out of synchronism with the natural vibrations of the pendulums, with the result that the armatures check the continuous swinging of the pendulums and thus do not allow the pendulums to swing through a large arc.

On the signal that it is desired to set, the pendulum of which corresponds to the master pendulum that the despatcher has set in motion, the arc of vibration of the pendulum will increase in a few seconds to an extent sufficient to trip a lock, thus releasing the semaphore arm, which falls by gravity to the horizontal stop position. The semaphore blade in moving closes a local signal-lamp circuit, which also indicates that the signal has been set at stop.

33. Another switch in a shunt circuit is also closed by the action of the semaphore blade. The signal pendulum in swinging now alternately opens and closes this shunt circuit from the signal line to the ground. The sounder at the despatcher's office is not operated by the comparatively small signal-current impulses; but when a shunt is formed to ground at any station, sufficient current will flow to pick up the armature of the sounder, and the armature will vibrate on account of the opening and closing of the circuit.

34. The clicking of the sounder notifies the despatcher that the signal has been set. The despatcher may then stop the master pendulum. The conductor of the car that is halted at the signal station calls up the despatcher by telephone for further orders. The conductor writes the orders on an autographic register and repeats them to the despatcher. He then takes one copy for himself and one for the motorman, while a third copy is left in the register. Then, if so instructed by the despatcher, the conductor pulls a cord that restores the semaphore to the clear position.

35. The connections for the signal system under discussion are shown in greater detail in Fig. 21. Three voltage-regulating relays *1*, *2*, and *3* are used to insert or to take out

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automatically the resistance in the signal-line circuit, so that the voltage across the terminals of the signal magnets may be kept nearly uniform, even when the railway line voltage is fluctuating. In some developments of this system, these relays are left out, as they are not vital to the proper operation of the signals.

Current flows from the positive conductor of the railway circuit at the despatcher's office–snap switch–*a*–*b*–*c*–operating coils of the three relays in series–ground at *G*. When the line voltage is 450 volts or higher, relay *1* draws up its armature and cuts out the shunt across the terminals of coil *15*. Current can flow from *a*–coil *21*–coil *15*–directly to the third terminal post from the left on relay *1*–terminal posts on relays *2* and *3*–conductor *d*, to which the circuit interrupting levers are connected–active lever–jack–plug, when in jack–sounder (signal current not sufficient to operate sounder) –coil *36*–signal line–ground at distant signal. Relay *2* draws up its armature at about 500 volts and cuts in resistance coils *16* and *17* in a manner similar to that just described, while relay *3* draws up its armature at about 575 volts and cuts in resistance coils *18* and *19*.

From *a*, current can flow through coils *22* and *23*–*e*–from this point, one path for the current is through the pilot lamps to ground, and the other path is to conductor *f*, to which the pendulum-moving magnets are intermittently connected –active lever–the magnet that is in action–ground at *G*.

36. The pendulums at the despatcher's office are normally latched back to the left, as shown in Fig. 21 (*a*). When a plug is inserted in a jack numbered to correspond with the number of one of the pendulums (see Fig. 19), that pendulum is released and starts to swing. The plug, Fig. 21 (*a*), raises slider *g*, which tilts lever *h* and releases pendulum *i*, as shown in the detail sketches (*a*) and (*b*). The upper portion of the pendulum engages pawls *j* and *k*, which operate switch levers *l* and *m*, respectively. These levers are arranged side by side. In the wiring diagram, they are shown one over the other in order that the connections may be clearly

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seen. Pawl *j* is so pivoted to lever *l* that it can move to the right, but not to the left, of its vertical position.

As the lower part of the pendulum swings on its knife-edge bearings from its left-hand position toward the right, the top portion of the pendulum is caught under the shoulder on pawl *j*. Pawl *j* and its lever *l* are raised, and contact between *l* and *n* is closed. The short lever *n* has a slight, free motion, and it is lifted as lever *l* rises in contact with it. As soon as the pendulum passes beyond its vertical position, its top portion moves out from under the two shoulders on pawl *j*, and lever *l* drops, breaking the contact between *l* and *n*. Contact is not made again until the lower portion of the pendulum has returned to its left-hand position and is once more swinging to the right, as the top of the pendulum cannot catch on pawl *j* except under these conditions.

Intermittent-current impulses are thus sent over the signal line by the action of the pendulum and contact levers *l* and *n*.

37. In order to keep the pendulum in motion, pawl *k* and contact levers *m* and *o* are provided. This pawl is pivoted to lever *m* and is free to swing in either direction. The right-hand point of the pawl is longer than the other point. When the pendulum is swinging through its full arc, its top portion flips by both points on the pawl without catching in the groove. As soon as the arc of vibration of the pendulum decreases, the top of the pendulum flips by the short point on the pawl, but not by the long point. This action occurs when the top of the pendulum is at the right-hand side of its swing. The top of the pendulum catches in the groove, and when it is moving back from the right toward the left —the lower portion of the pendulum then moving from the left toward the right—pawl *k* and lever *m* are raised, thus completing the circuit through levers *m* and *o* and the 63-ohm actuating magnet.

The armature of the magnet is drawn toward the core, and a projection of the armature strikes the pendulum below its bearing point and gives it a push toward the right, which

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is in the same direction as it is swinging. This push increases the arc of the swing, so that the top of the pendulum again flips by both points on pawl *k*, and levers *m* and *o* are not active until the arc of the swing of the pendulum has again decreased.

The device is practically a magnetic clock so arranged that the pendulum can neither come to rest nor be so energized that it will swing beyond a certain arc.

38. Assume that the despatcher wishes to set the signal at stop in station No. *1*. The plug is inserted in jack No. *1*, Fig. 19, or near the first pendulum on the left, Fig. 21. The pendulum is released, and thus causes the lever *l* actuated by it to send current impulses over the signal line. All the signal magnets are energized, but since these impulses are synchronous with only the natural vibration of the pendulum at station No. *1*, only the signal at this station will be operated.

When the pendulum at the outside station has swung far enough, a trip releases the semaphore arm, which falls to stop position, as indicated at the right-hand side of Fig. 20, and thus closes mechanically two switches, as shown in Fig. 20 and in the lower right-hand portion of Fig. 21. The trip mechanism is shown in Fig. 20. The pawl on the tripping lever is free to move in either direction. The pawl is offset from a vertical line through the center of the pendulum bearing. The right-hand point of the pawl is longer than the other point, and the left-hand point on the top portion of the pendulum is longer than the other point. When the pendulum is swinging through only a small arc, the short point at the top of the pendulum does not get under the pawl and the trip is not operated. When the arc of vibration is great, the short point catches under the pawl and the trip is operated. Current can flow from the 550-volt circuit near station No. *1*, Fig. 21, through two resistance coils–switch *p* (now closed)–signal lamp *q*–20-ohm magnet coil *r*–ground at *G*. Lamp *q* is lighted, and the armature of magnet *r* is pulled up and a contact at *s* opened, as shown at station

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No. *15*. Current cannot flow through lamp *t*, station No. *1*, because of the open circuit at *s*.

39. If lamp *q* burns out, coil *r* is demagnetized and contact *s* is closed. Current can now flow from switch *p*–lamp *t*–63-ohm magnet coil *u*–frame–armature of coil *r* –contact *s*–*G*. Magnet *u* attracts armature *v*, which turns in a counter-clockwise direction and closes contact *w* (normally open). This action connects a shunt around lamp *t* and coil *u*. Most of the current flows through the low-resistance shunt. Lamp *t* is extinguished, magnet *u* is weakened, armature *r* rotates to its former position by gravity, and contact *w* is again opened. Lamp *t* now burns with normal brilliancy, magnet *u* again attracts its armature *v*, and the shunt is active in extinguishing the lamp. The flickering of lamp *t* calls attention to the disorder in the circuit of lamp *q*.

40. A lifting pawl closes contact *x* at each swing of the pendulum. A shunt to the ground from the signal circuit through switch *y* is thus intermittently opened and closed.

Enough current can now flow through the answer-back sounder at the despatcher's office to operate this sounder, and in doing so it gives notice that the outside signal-station semaphore is set at stop. The rapidity of the clicks made by the sounder depends on which signal pendulum is opening the circuit. The right-hand binding post and the lower contact are not active electrically when this relay is used as an answer-back sounder. After the outside semaphore has been set at danger, the master pendulum at the despatcher's office is stopped; and after the message has been delivered, the outside semaphore is returned to the clear position.

LOCATION OF AUTOMATIC BLOCK SIGNALS

41. Conditions Controlling Location. — In order to secure the safe maximum capacity for train movements over a given piece of track, it is necessary to know the maximum distance required for stopping the fastest train on the road. Air-brake tests will determine this distance, and for

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maximum train capacity, the length of the block should be equal to this value, but should not be less.

Since it is more difficult to stop on a descending grade and less difficult to stop on an ascending grade, the blocks should be lengthened on descending grades and shortened on ascending grades. As large terminals are approached, the blocks should be shortened on account of the limited speed of trains and the congestion of traffic at such places.

Having fixed the locations, the control of the signals should be such as not only to warn the motorman when he reaches a block that is occupied, but also to warn him in time to permit him to stop his train before reaching the entrance of the occupied block. With this arrangement and control of signals, it would be possible to start two trains from one end of the line, space them two blocks apart, run them the length of the road at the same speed, and have them arrive at the other end still two blocks apart. The second train would receive clear signals all the way; or, if the first train should stop at any point, the second would receive due warning and have plenty of space in which to stop before reaching the block occupied by the first train.

Certain extracts utilized in some of the following descriptions of signal systems are from the Electric Journal.

42. Arrangement of Blocks.—In Fig. 22 is shown an arrangement of an automatic block system using semaphore home and distant signals mounted on separate posts. The ends of the home-signal arms are square, while the ends of the distant-signal arms are forked, or fish-tailed. The

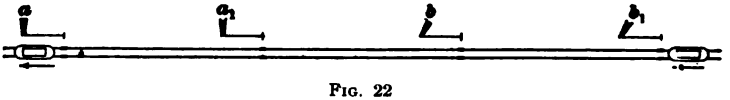

FIG. 22

home signal a is shown in the stop position, with a train just past it in the block. The arm is horizontal, and a red light would be displayed at night. The distant signal for a is shown at a_1. This signal is in the caution position, meaning to an approaching train, "expect to find the next home

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signal in the stop position." Home signal b is in the proceed position, since the train has just moved out of the block $a\ b$, the signal arm being inclined at an angle of 60° or 75°, and in some cases 90° from the horizontal. Under this arrangement, trains can be run at full speed, provided they are spaced a distance equal to one block (a to b) plus the distance between a home signal and its distant signal (b to b_1).

43. The indications and meanings of the signals shown in Fig. 23 are identical with those described in Fig. 22. This

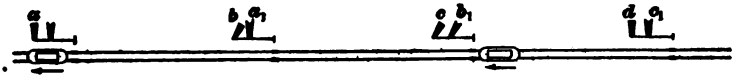

FIG. 23

arrangement is developed by shortening the length of blocks $a\ b$, Fig. 22, until a_1 and b, Fig. 23, are so close together that it is best to mount them on the same post. Distant signal b_1 has just gone to clear, since the train has passed out of block $a\ b$. With this arrangement, trains running at speed would be spaced two blocks apart, although the actual distance might be the same or shorter than that shown in Fig. 22.

44. Fig. 24 shows an **overlap system,** where the overlap is a half block in length. Overlap systems are such

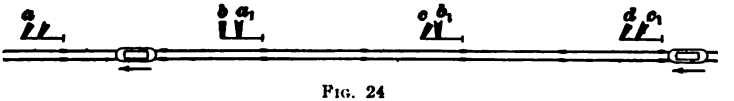

FIG. 24

arrangements of signals and their circuits that trains may be spaced one, two, or as many blocks apart as may be desired. From a to b is one block, from b to c another block, etc. Each block, however, is cut in half, as shown by the insulated joints in the track. The train, which is at a point just beyond the middle of the block $a\ b$, has kept the signals c and c_1 in the stop and caution positions, respectively, until this point was reached. Therefore, the overlap beyond the next home signal b is one-half the distance from a to b. With this

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arrangement of signals, trains could be spaced two and one-half blocks apart and be allowed to run at full speed.

Fig. 25 shows a full-block overlap. This arrangement permits trains to be spaced three blocks apart and allows them to be run at full speed. Signals c and c_1 have just been set to clear position.

45. Where home signals only are used, the overlap is necessary, because in many cases local conditions will not permit signals to be located so that they are visible at a safe stopping distance away. The distant signal takes the place

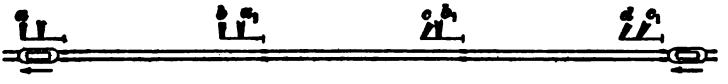

FIG. 25

of the overlap, except where the blocks are extremely short.

The problem of overlap is one that may be given much consideration. Conditions may arise that may cause a motorman to run by a home signal in the stop position. The overlap gives additional space to stop in, but there is a question whether or not it should be used except in unusual cases where the blocks are very short on account of traffic. The overlap is open to the objection that if a motorman knows there are at times two stop signals between him and the train ahead, he may assume that there are always two stop signals between, and run by the first one without attempting to stop, thereby courting great danger.

46. Automatic signals are usually so constructed that they will gravitate to the stop position when any part of the signal or the signal system is deranged. The signals are counterweighted sufficiently to carry the arm of the signal to the stop position by gravity. From this fact it is evident that some source of power is necessary to move the arm to the clear, or proceed, position and to hold it there. The type of signal dealt with in the following descriptions of automatic block systems is the *semaphore signal.* The signals are operated by compressed air or by electric power applied

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to electric solenoids or to motors, or by a combination of air and electric power.

The control of these various applications of power lies in the track circuit, which is the foundation of any automatic block system. The track circuit is so connected that a train passing a signal set at the proceed position will cause the power that holds the signal in that position to be cut off from the signal apparatus and thus allow the signal to gravitate to the stop position.

In the systems to be described, all signal circuits are so arranged that a closed circuit is employed to give all safety indications, thus causing a danger indication to be displayed when any wires are crossed or broken or when the system is in any way deranged.

47. On steam roads, where both rails can be used for carrying current for signal work, the track circuit takes the

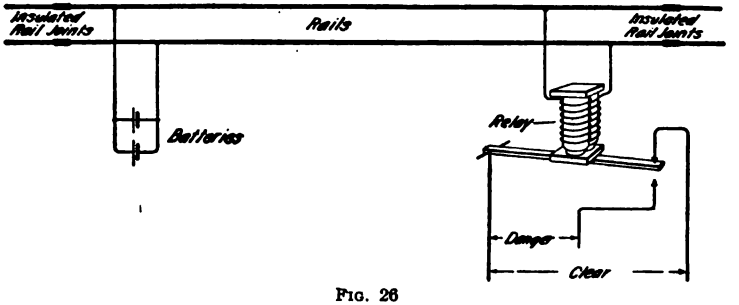

FIG. 26

form shown in Fig. 26. The installation of a section of track circuit necessitates the replacement of the iron fish-plate joints at each end of the section with an insulated joint; the bonding together of the intermediate rails by running bonds of wire around each joint; and the connection of a battery across the rails at one end of the section and the connection of an electromagnet, or relay, at the other end. The relay has a pivoted armature that carries contacts for controlling the signal, or auxiliary, circuits. The armature falls away from the magnet cores by gravity and requires that the magnets be energized in order to raise it. The track circuit is a

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closed circuit, and the relay is normally energized. The breaking of any wire in this circuit or the short-circuiting of the relay, caused by crossed wires or a train on the track circuit—in which event the wheels and axles cause the two rails to be connected together—will cause the relay armature to fall away from the cores, breaking the circuit that holds the signals in the clear position and causing them to go to the danger position.

On electric roads, the running rails are used for the propulsion current, and bonds connect adjacent rails together. Other circuits have therefore been designed to meet such conditions, but they all adhere to the principle just outlined.

DIRECT-CURRENT AUTOMATIC BLOCK SIGNAL

BOSTON ELEVATED-RAILROAD SIGNAL SYSTEM

48. Description of Apparatus.—The direct-current, automatic block-signal system about to be described is the one installed on the elevated railroad in Boston, Massachusetts, and is adaptable to any double-track service where expense of installation is secondary to safety. The system is unique in that one line of rail of each track is reserved for signal-circuit purposes and is divided into insulated sections, or blocks. The remaining line of rail of each track serves in the usual way as a ground return for the train-operating currents, the track rails being bonded together and to the steel elevated structure at frequent intervals so as to increase the current capacity of the return part of the circuit. The device of using one of the track rails as a signal-circuit conductor is much more practicable on an elevated railroad than it would be on a surface road, because on such a road there is no metal structure to be connected in parallel with the remaining return rail, and the cross-ties, being embedded in earth, cannot be relied on as signal-circuit insulators so well as can those on an elevated road. Great care is taken to prevent any electrical communication between

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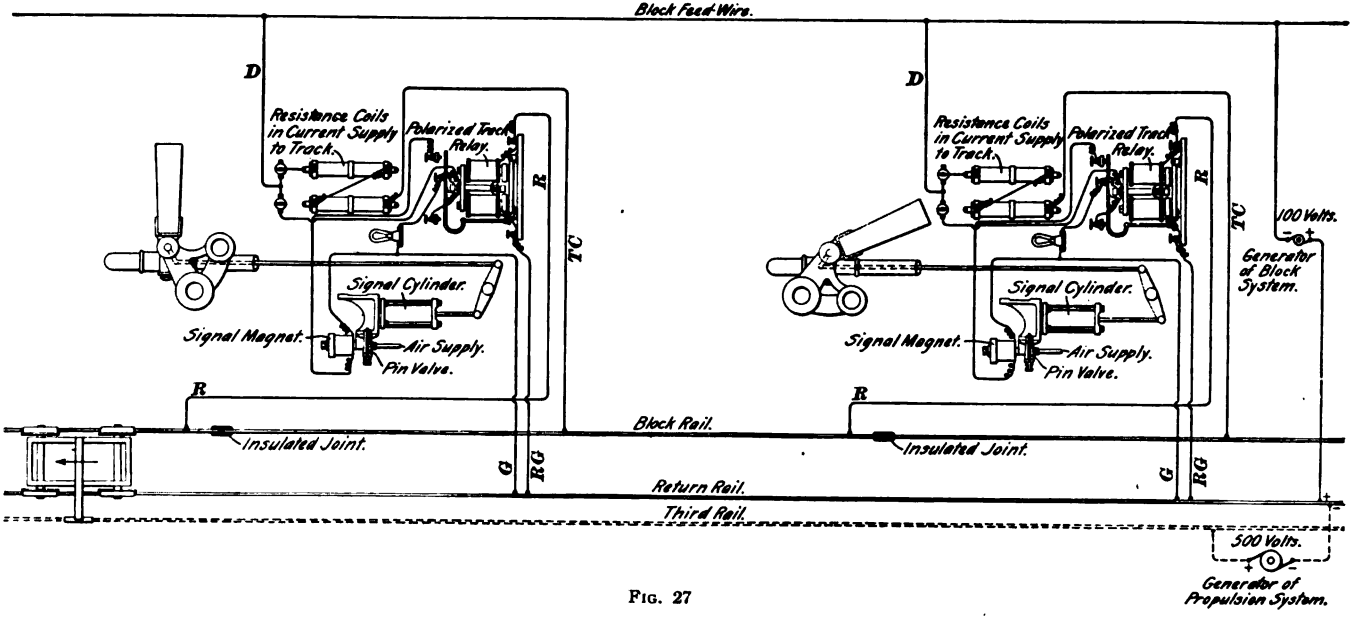

FIG. 27

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the signal track rail and the ground-return track rail, except in so far as they may be connected through conductors necessary to the signal system. Insulation separators are used at switches, crossings, and any other place where the two track rails would ordinarily be connected. The bonds between abutting ground-return track rails and the bonds to the structure must be substantially installed and properly maintained.

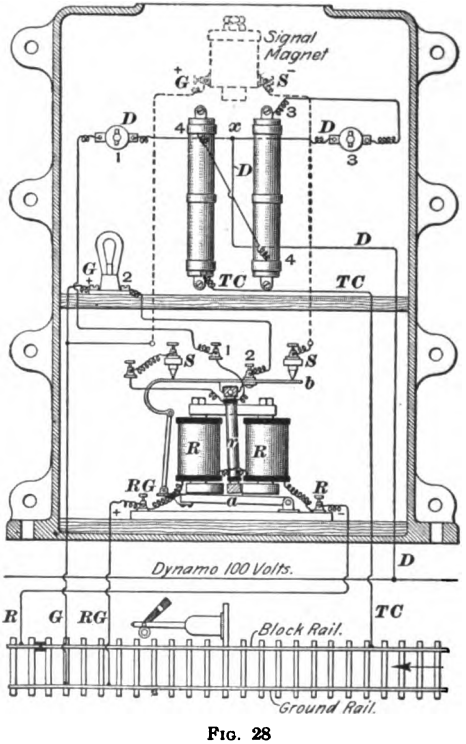

FIG. 28

49. The signal system itself comprises a combination of electrical and compressed-air apparatus and is called the *electropneumatic system*. A 100-volt motor-generator driven by current from the railway power circuit furnishes the current for the signal devices that operate the air valves controlling the admission and the exhaustion of compressed air to and from the signal cylinders. The electrically controlled air cylinders automatically operate the semaphores and dependent safety devices. Since the signal-current supply is primarily dependent on the same generators as the train-current supply, when the line is dead the signal service is dead also, so far as indicating safety is concerned.

The supply of compressed air for operating the semaphores and dependent devices is obtained from both motor-driven

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and steam-driven air compressors located at terminal stations, and is delivered to the pneumatic operating cylinders by a pipe line extending the full length of the elevated structure.

50. In Fig. 27 is shown the scheme of track circuits for a complete signal section, or block. Fig. 28 shows more clearly the connections inside of one of the signal-operating boxes. In Fig. 27, the 100-volt signal dynamo is shown connected between the ground-return rail on one side and the supply wire, or *block feed-wire*, on the other side. The block feed-wire extends the full length of the system, a tap connecting it to each operating box, as indicated at *D*, Figs. 27 and 28.

Fig. 28 shows that tap *D* connects to the stretch of circuit *D*–*D*–*D*–*x*–*D*–switch *3*–*3*–resistance coil–*4*–*4*–resistance coil–*TC*–*TC*–*TC*–block-signal track rail. Each resistance coil has a resistance of 100 ohms; therefore, the two coils in series provide a total resistance of 200 ohms. The block feed-wire, or signal-current supply wire, then, taps to the block track rail at each signal-operating box through a resistance of 200 ohms.

51. Operation.—The two stationary electromagnets *R* and the swinging electromagnet *r*, Fig. 28, constitute what is called a *relay*. When coils *R* are energized, they attract their armature *a*, which in turn lifts contact maker *b* into connection with the left-hand contact *S*. This action closes the circuit of *r* through the path: ground rail–lamp–*2*–*2* on *b*–left-hand contact *S*–*r*–*1*–*x*–*D*–block feed-wire. The electromagnet *r* is so magnetized that its lower pole piece is attracted to the right-hand pole piece of the stationary magnets *R*, and the contact maker *b* is bent into contact with the right-hand contact *S*. Current can now flow from wire *G*–signal magnet–*S*–*b*–*S*–*r*–*1*–*x*–*D*–block feed-wire.

When the signal magnet gets current, which is impossible unless relay magnets *R* are energized so that spring contact maker *b* closes the signal-magnet circuit between contacts *S*, the signal magnet opens a valve that admits compressed air

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into the operating cylinder of the semaphore, thereby causing the semaphore to set at clear, or safety.

52. Figs. 27 and 28 will now be considered in order to determine under what conditions the relay operates to close the signal-magnet circuit and thereby keep the semaphore at safety. In Fig. 28, coils *R* of the relay are in series and are permanently connected between the ground rail and the block rail of the section, or block, to be protected by way of the path: ground rail–*RG*–*RG*–*R*–*R*–*R*–*R*–block track rail.

Assuming that there is no train on the complete block shown in Fig. 27, the semaphore at the rear of the block, that is, the one indicated near the right-hand box in Fig. 27, will be at safety. The signal at the rear of the block to be protected has its relay coils connected across the block rail and track ground-return rail of that block, and the signal at the forward end of the block, Fig. 27, also has a permanent connection between the block feed-wire and block rail. As long as there is no train in the block, current from the return rail flows through the relay coils of the rear signal box, along the block rail, through the resistance coils of the forward signal box, and then to the block feed-wire. In this manner, the armature of the relay in the rear signal box is kept in its upper position, where spring contact *b*, Fig. 28, keeps the signal-magnet circuit closed. This, in turn, keeps open the air valve that admits the compressed air into the control cylinder that is effective in keeping the semaphore and its connections set to safety.

The instant that a train enters the block, thereby short-circuiting the relay coils by connecting the block and track ground rail by means of the car wheels and axles, the armature of the relay drops. In dropping, this armature pulls down spring contact arm *b*, Fig. 28, and opens the circuit of the signal magnet, so that the magnet can no longer hold open the valve that controls the admission of air to the cylinder that retains the semaphore and its attachments at safety. Accordingly, the instant a train enters the block the semaphore at the entrance of the block goes to danger. This

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action is similar to that explained in connection with Fig. 26.

53. In Fig. 27, a car or train has passed off the complete block and has just entered the block at the left, on which the truck of a car is indicated. The instant that the train passed off the complete block, the short circuit being removed from the relay coils of the rear signal, the semaphore at that end went to clear. Simultaneously, however, the block and track rails of the next section—the section on which the truck of the car is indicated—being short-circuited by the axles of the train, and the relay of the signal box at the entrance to that block becoming dead, its dependent semaphore is moved to danger, as indicated by the position of the semaphore arm of the signal shown at the left of the figure.

In any given signal box, the current that energizes the relay coils in that box and keeps the signal-magnet circuit closed and the semaphore at safety when there is no train in the section flows from the block feed-wire connection of the signal box at the beginning of the next block. The stretch of circuit that connects the block feed-wire to the block rail at every signal box and includes the two 100-ohm resistance coils always carries current, because when the circuit to the track rail is not completed by a train on the block, it is completed by the relay coils of the next signal box.

54. The signal magnet, then, can get current only when there is no train in the block, because only then are the relay coils energized so that they can pick up their armature and cause spring contact *b*, Fig. 28, to close the signal-magnet circuit. As long as the signal magnet is energized, it holds open a valve that admits compressed air to the live side of the semaphore piston, which pushes the semaphore to the clear, or safety, position. As soon as the entrance of a train to a block short-circuits the relay of the protecting signal box, thereby opening its signal-magnet circuit, a valve opens, releasing the air and permitting the semaphore to move to danger. The semaphores are held at safety by air

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admitted by the signal magnet, but they fall to danger as soon as the air is allowed to escape.

55. Features of Safety.—At *r*, Fig. 28, is shown a swinging electromagnet, the winding of which is connected in series with the parallel circuit consisting of the signal magnet and the lamp. The passage of current through the winding of *r* makes one end of the magnet a north pole and the other end a south pole. The bottom pole piece of one of the stationary relay magnets is a north pole, and the bottom pole piece of the other is a south pole. The lower pole of *r* is attracted to one or the other of the pole pieces of the relay magnets *R*, depending on the relative polarities of the pole pieces. Ordinarily, the swinging magnet takes the position shown in Fig. 28, where its pole is attracted to the right-hand relay-magnet pole. In Fig. 27, the third rail, or the contact rail from which the trains derive their motive power, is connected to the positive side of the power station. The contact rail is thus positive. The negative side of the power-station generator is connected to the ground-return rail. The positive side of the 100-volt dynamo that supplies the current for the signal system is, however, connected to the ground-return rail, while its negative side is connected to the block feed-wire.

56. Suppose that a train entering the complete block, Fig. 27, should run on ice or sand on the ground-return rail, but not on the block rail, so that the relay coils *R*, Fig. 28, are not short-circuited by the axles and the coils still take current with which to keep the signal-magnet circuit closed and the semaphores at clear. Under such a condition, Figs. 27 and 28, when the power is applied to the train in the block, the current, instead of entering the temporarily insulated ground-return track rail after having passed through the car motors, follows the block rail to the relay and passes through the relay in the opposite direction to that ordinarily taken by the current from the 100-volt signal circuit. From the relay magnets, the current can then flow to the ground-return rail and back to the negative terminal of the 500-volt,

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power-station generator. The reversed current reverses the polarity of the relay stationary pole pieces, while the polarity of the swinging pole piece, which is energized from the 100-volt dynamo, is the same as before.

The result is that, although the reverse current does actually operate the relay and tend to energize the signal-magnet circuit and keep the semaphore at clear with a train in the block, such a dangerous condition cannot actually happen, because the reversal of polarity of the relay magnets *R*, Fig. 28, causes the swinging pole piece of *r* to move over to the left-hand relay pole piece, thereby springing contact maker *b* away from right-hand contact post *S*, which connects to the signal magnet. The signal-magnet circuit is now open and the semaphore is set at danger.

As soon as the left-hand movement of the swinging pole piece causes spring contact *b* to spring away from the right-hand contact post *S* and to open the signal-magnet circuit, the current that ordinarily passes through the signal magnet passes through the lamp by way of post *2* mounted on spring contact maker *b*. Were no lamp or its equivalent provided to bridge the open circuit in the signal-magnet circuit, all current flow through swinging magnet *r* would cease and its pole piece would become weak. The left-hand stationary pole piece, however, would still attract the pole piece of the swinging coil and thus hold the signal at danger.

57. A relay of the type just described is called a **polarized relay,** because its armature has well-defined magnetic poles. The armature of the relay will be attracted toward the stationary pole piece, which is of the opposite polarity to that of its freely moving end. Reversal of the polarity of the stationary pole pieces or of the polarized armature (but not both), results in a reversal of the direction of motion of the armature. Polarized relays for signal work are, however, designed so that the change of polarity occurs in the pole pieces only and not in the armature.

If the polarized member of the relay were omitted, and a train should happen to run into the block when there is ice

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or sand on the ground-return rail, the relay would be operated by the reverse current as soon as power was applied, and the semaphore would be kept at safety. Again, if the negative ends of both the signal-service dynamo and the power-station dynamo were grounded, the polarity of the stationary-relay pole pieces would be the same, whether excited from the 500-volt railway current or from the 100-volt signal current; therefore, there would be no agent tending to pull swinging magnet *r* to the opposite side, as just described. The connection of the block-signal dynamo, therefore, must be as indicated in order to realize the benefits of a polarized relay.

INTERBOROUGH ELEVATED-RAILROAD SIGNAL SYSTEM

58. The apparatus and circuits for a typical block section as installed on the elevated lines of the Interborough Rapid Transit Company, of New York City, are shown dia-

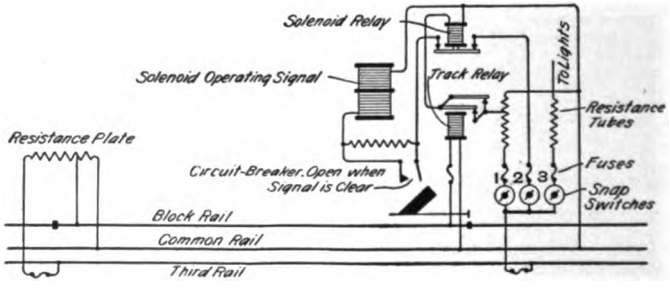

FIG. 29

grammatically in Fig. 29. Semaphore signals operated by solenoids are used, while the current for the signal system is taken from the third rail. One of the track rails is insulated for the block sections. The blocks vary in length according to track conditions. At the outgoing end of the block, the third rail is connected through a fuse to a resistance plate having two taps at the upper end. One of these taps is connected to the block rail, and the other to the common rail, which is grounded for the return power circuit.

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The resistance is adjusted so as to give a difference of potential of 10 volts between the two track rails. At the entering end of the block, the two track rails are connected together through a two-point track relay. This relay is wound to pick up its armature when a potential of 3 volts is impressed across its terminals. Thus, even if the line voltage varies to a considerable extent, there will still be enough electromotive force across the terminals of the relay to operate it.

59. At the semaphore signal, a tap from the third rail connects to a bus-bar on which are mounted three snap switches. When no train is in the block, the track relay is energized and its two contacts are closed. Current from the third rail passes through switch *1*–resistance–track-relay armature –solenoid-relay coil–thence to the common rail, or ground. Current also flows through switch *2*–armature of solenoid relay–resistance of 3,000 ohms–solenoid coil–thence to ground. The signal is held in the proceed position. The 3,000-ohm resistance is inserted in the circuit so that the power required to hold the signal in the proceed position will be reduced to a minimum.

When a train enters the block, the axles and wheels short-circuit the track relay. This action causes the armature of the track relay to open the circuit through the solenoid relay, whose armature, when it drops, opens the circuit of the signal-operating solenoid. The signal arm then falls by gravity to the stop position.

An oil dashpot is provided to cushion the shock of the moving arm. When the train passes out of the block the track relay picks up, causing the solenoid relay in turn to pick up. A current then flows through the solenoid-relay armature, the circuit-breaker, which is closed when the signal is at stop, and the signal-operating solenoid, to ground. The large current in the signal solenoid moves the signal to proceed, but as soon as the arm reaches this position, the circuit-breaker opens, cutting the high resistance in circuit and allowing only a small current to flow through the solenoid.

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60. In Fig. 30 is shown a type of *high semaphore signal* with the doors in the lower case open so as to show a portion of the signal mechanism. The solenoid plunger, shown at

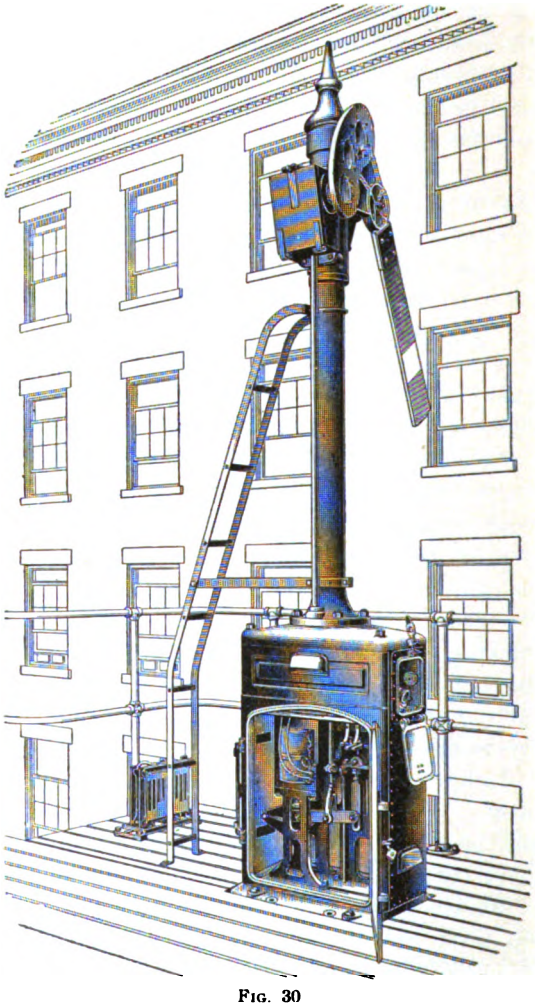

FIG. 30

the left, is connected to a pivoted lever to which a dashpot is fastened. The signal pull rod is fastened about midway between the solenoid plunger and the dashpot. Resistance

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tubes are mounted on one side of the case, and the circuit-breaker attached to the signal rod can be seen just above the dashpot. In the upper part of the case are located the two relays and the snap switches.

This type of semaphore signal, as shown, has three spectacles, the two top ones being red and the lower one clear or some color indicating safety. By this means, there is continuous light from one signal position to the other. There is no transitory dark position as might be the case if only two widely spaced spectacles were used.

ALTERNATING-CURRENT AUTOMATIC BLOCK SIGNALS

SINGLE-RAIL RETURN

61. Where the track rails conduct current used for the propulsion of electric trains, this current causes a drop of potential along the track rails of varying value, and these variations in potential set up disturbances in a signal circuit that includes the track rails. In order, therefore, to use the rails for both signaling and traction purposes, alternating current is used on some roads for the signal system and track relays are installed that operate only by alternating current. In some systems, one rail is used as a block-signal rail, and the other rail is used for the ground return of the propulsion current and for the other side of the alternating-current signal circuit. In another system, both rails are used as block-signal rails as well as for the ground-return path for the propulsion current. The **single-rail return system** will be described first.

62. New York Subway Signal System.—An installation of the single-rail return system employing alternating current for the signals is used in the New York Subway. All the automatic block signals, automatic train stops, and the interlocking switch and signal plants, which are semiautomatic, are of the electropneumatic type.

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63. In Fig. 31 is shown diagrammatically the more important signal connections of a block. The alternating current for the signal mains is generated by a turbine generator. The usual manner of arranging the track circuit is to supply alternating current from one of the secondary coils of a transformer *a* to the end of the block from which trains leave, and to connect the track relay *b* to the end of the block into which trains enter.

Since propulsion current from trains in other blocks passes through the return rail, there will be a difference of potential between *c* and *d*. As very little propulsion current flows

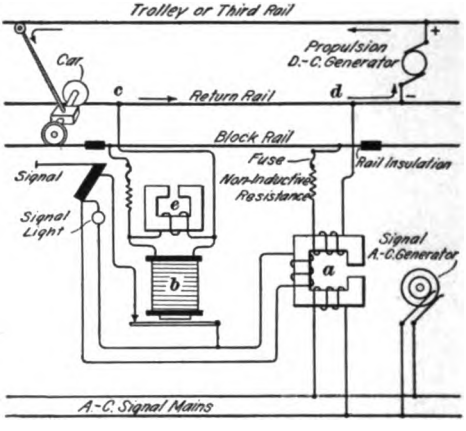

FIG. 31

through the block rail, the drop of potential due to direct current in that rail is not very great. The difference of potential between *c* and *d*, however, forces some direct current to flow from *c* through the track relay *b* and its inductive shunt *e*, the block rail, and the secondary of the transformer *a*, to *d*. Resistances are connected in circuit with the track relay and with the secondary of the transformer. An impedance coil *e* of low ohmic resistance is connected across the terminals of the track relay *b*, and both coils *a* and *e* have cores provided with air gaps, in order to reduce the magnetizing effect of the propulsion current. The direct current is small, and as the track relay is oper-

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ative only on alternating current, the propulsion current has but little effect on the signal system.

64. When the block has no train in it, the alternating

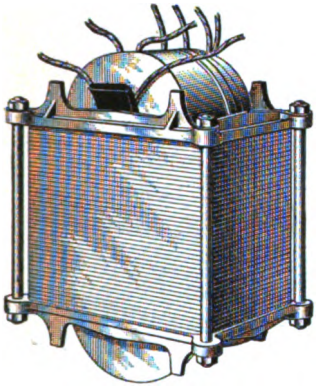

FIG. 32

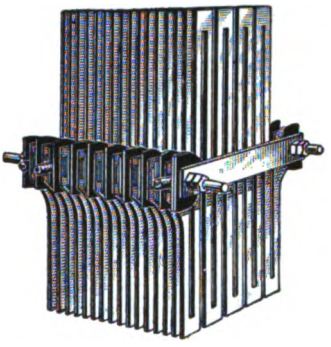

FIG. 33

signal current from one of the secondary coils of the transformer *a* can flow through the rails and the track relay and thus operate the track relay to set the clear signal. When a train enters the block, the wheels and axle short-circuit the track relay, which then operates to set the danger signal.

65. In Fig. 32 is shown the track transformer. The electromotive force of the signal mains is 500 volts; that of the secondary coil of the transformer connected to the track, 10 volts, and that of the other secondary coil, which is connected to the signal light, 55 volts.

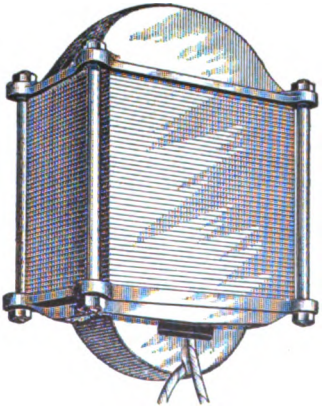

FIG. 34

In Fig. 33 is shown the form of non-inductive grid resistance used, and in Fig. 34 the low-resistance impedance coil that is shunted across the track relay.

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66. In Fig. 35 is shown a track relay with the lower cover removed so as to expose the movable vane *a*. The energizing coils *b* have laminated pole pieces, portions of which are enclosed by a conductor short-circuited on itself. When the alternating signal current flows through coils *b* currents are induced in the short-circuited conductors in the pole faces. The distorted field of alternating polarity brought

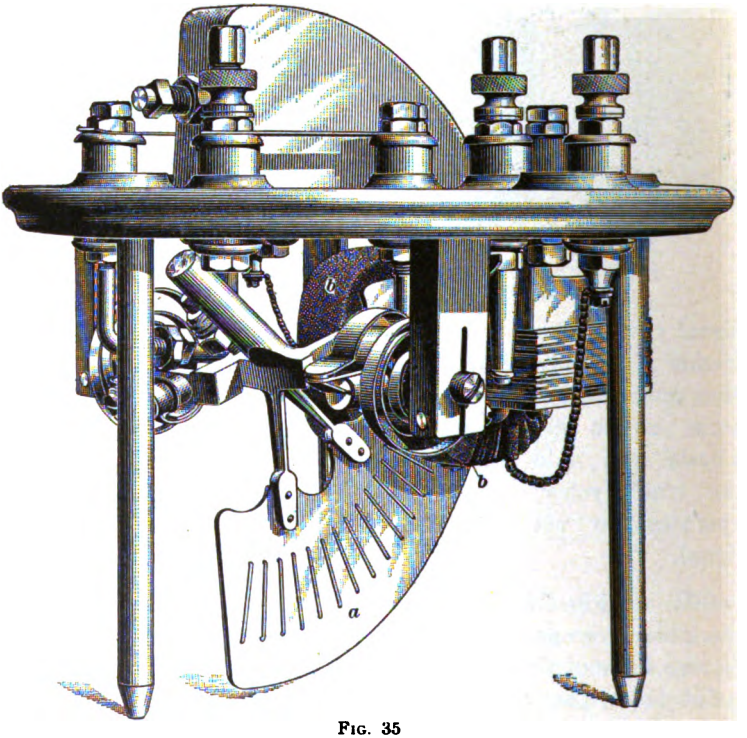

FIG. 35

about by the magnetizing action of these currents, when acting on the magnetic field set up by the eddy currents induced in the vane, causes the vane to rotate to its highest position. In this position, the circuits are closed and the signal lights thus set at clear.

As long as the normal value of alternating current flows through the coils *b*, the vane will remain in its clear position.

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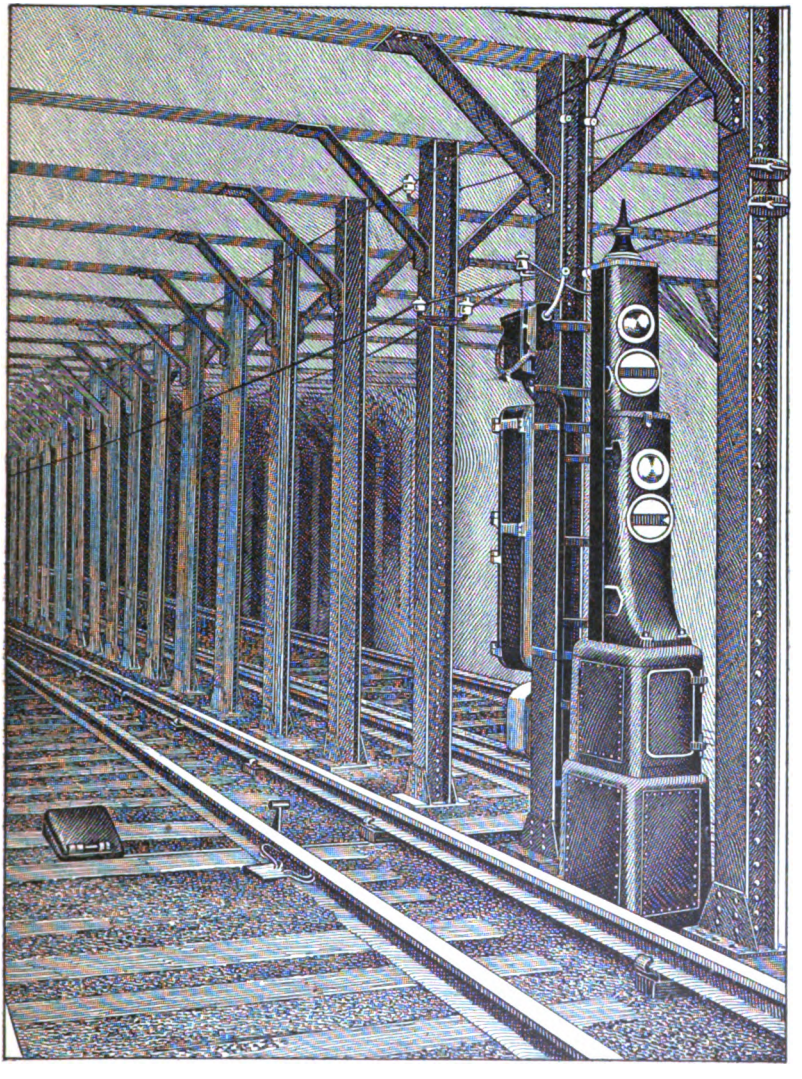

FIG. 36

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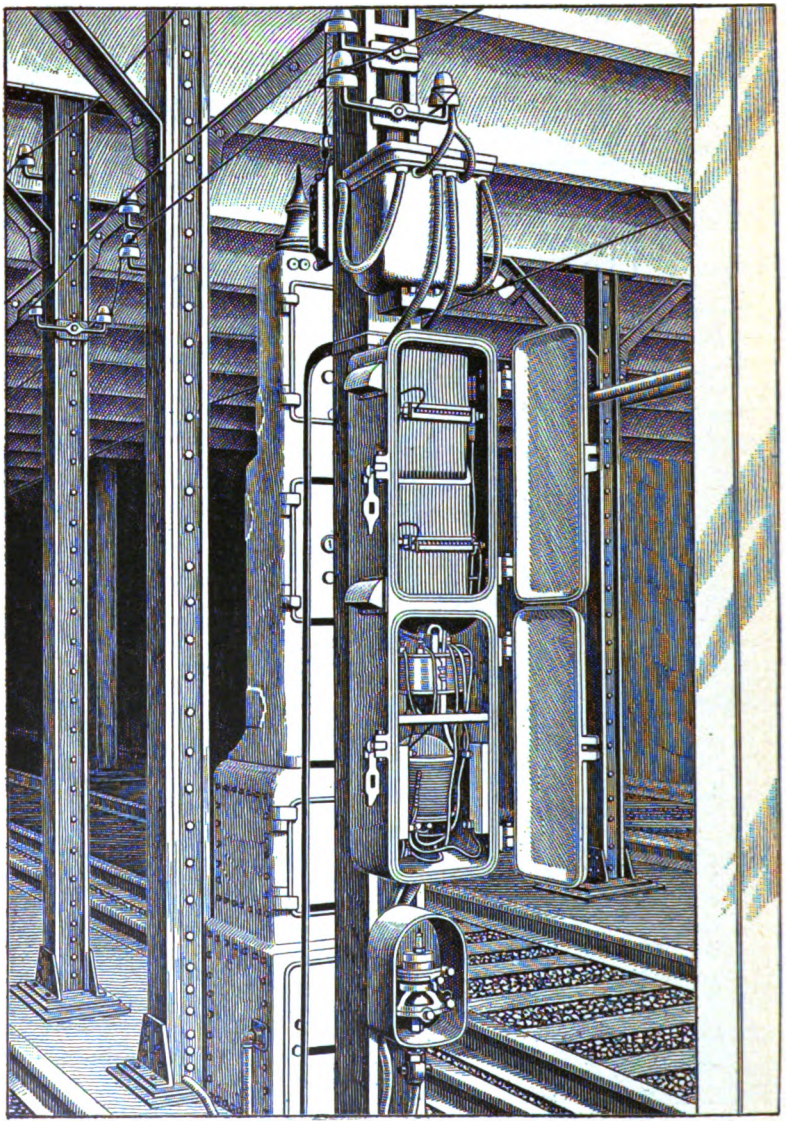

FIG. 37

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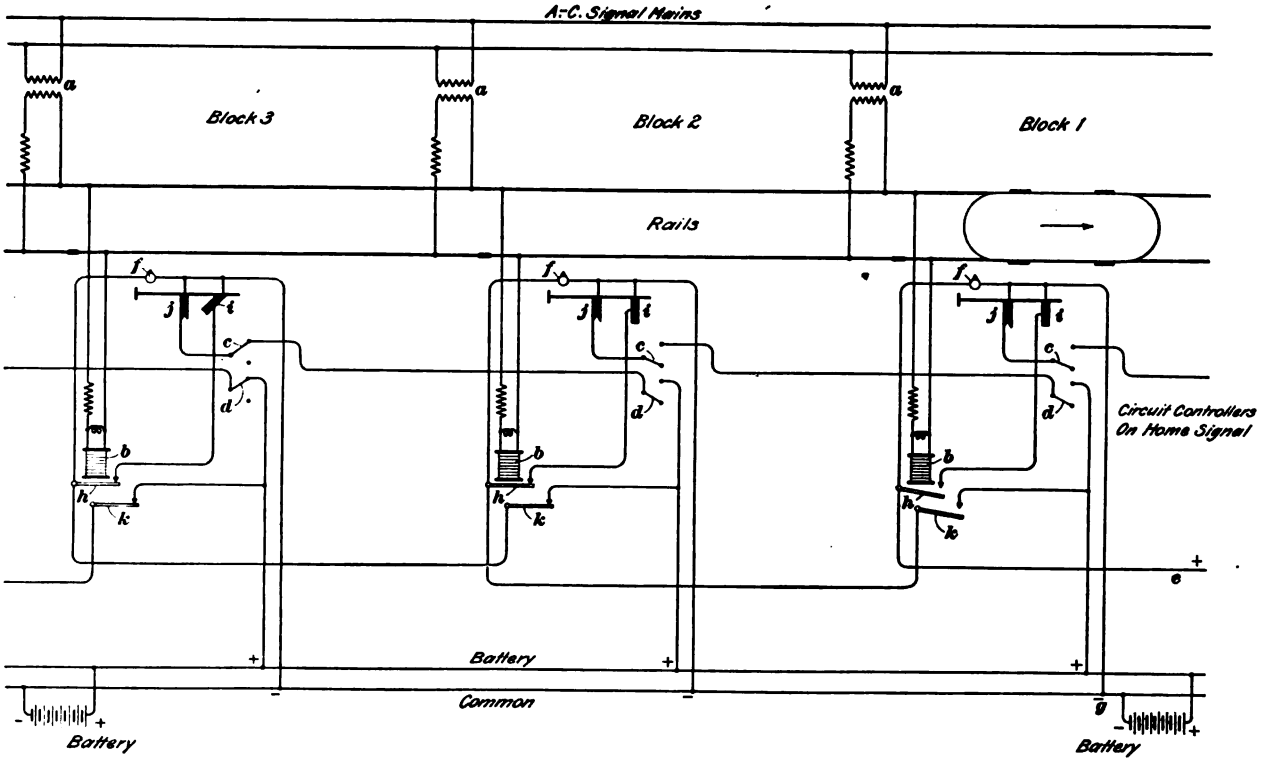

FIG. 38

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On the shaft of the vane are mounted contact pieces forming part of the control switches. These contact pieces are actuated by this shaft and the control switches control the circuits that operate small magnets. These magnets, in turn, operate air valves that control the admission of air to the movable signal mechanism.

67. In Fig. 36 is shown the front of a signal case containing the signal lights, the small semaphore signals, and the pneumatic mechanism as installed in the New York Subway. Fig. 37 shows another case mounted behind the signal case and containing the resistance grid, the impedance coil, and the track relay. The electropneumatic valve for controlling the automatic train stop is shown near the bottom of Fig. 37, while the train stop itself is shown near the track rail in Fig. 36. This device operates to stop the train by applying the train air brake in case the danger signal is disregarded.

68. New York Subway Signal Wiring Diagram. In Fig. 38 is shown in more detail a wiring diagram of the New York Subway signal system, in which the circuits operating the electropneumatic signal valves are indicated. The track transformers are shown at *a* and the track relays at *b*. Each home signal operates two switches *c* and *d*. These switches are closed when the home signal is at the clear position, and open when it is at the stop position.

When current flows through the magnets operating the electropneumatic valves, the signals are kept at clear by air admitted through the valves. When current ceases to flow, the air under the signal pistons is released and the signals fall to the stop position.

69. A train is in the block at the right, Fig. 38, and the two switches controlled by the track relay for that block are therefore open. The wire *e* is connected to the + battery wire of the block at the right of the one in which the train is moving by means of the closed lower relay switch in that block. Current can therefore flow from *e* through the

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electropneumatic valve *f*, block *1*, that controls the automatic train stop, and then to the −battery wire at *g*. This train stop is then held down and does not interfere with the train that is passing through the block.

70. On account of the train in the block, the upper relay switch *h*, block *1*, is now open. Therefore, current cannot flow from *e* through *h* to the home-signal control magnet. The home-signal *i* thus falls to the stop position, and in doing so it opens switches *c* and *d*.

The opening of switch *c*, block *1*, causes distant signal *j*, block *1*, to go to the stop position. The opening of switch *d* cuts off battery current from distant signal *j*, block *2*, and that signal therefore falls to the caution, or stop, position.

The opening of the lower relay switch *k*, block *1*, cuts off the battery current from home signal *i*, block *2*, and that signal therefore falls to the stop position.

On moving to the stop position, home signal *i*, block *2*, opens switches *c* and *d*, block *2*. The circuit of *c* is already opened at *d*, block *1*. Switch *d*, block *2*, opens distant signal *j*, block *3*.

Home signal *i*, block *3*, is held in the clear position, since its control magnet can get current from switch *k* (closed), block *2*, and switch *h* (closed), block *3*.

The control magnet of the automatic train stop *f*, block *2*, is deprived of current by the open switch *k*, block *1*. In case the danger signals of block *2* are disregarded, the automatic train stop will cause the train to be halted.

71. The danger warnings set up by the train in block *1* are as follows: The home and distant signals at block *1* are at danger and caution; the home and distant signals at block *2* are at danger and caution; the distant signal at block *3* is at caution; and the train stop at block *2* is in a position to halt any train that passes the danger signal at block *2*.

By this system of overlap, a train is always protected from a rear-end collision by two home signals and three distant signals set at either the danger or the caution position;

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in addition, an automatic train stop is active in the block just behind the one in which the train is located.

72. The small amount of space available in the Subway does not permit the common type of semaphore arms to be used; therefore, colored-light signals are employed. Suitable colored glasses are mounted in slides and are moved into position in front of incandescent lamps by the action of compressed-air cylinders. Distant signals show a yellow light for caution, while a home or a dwarf signal shows a

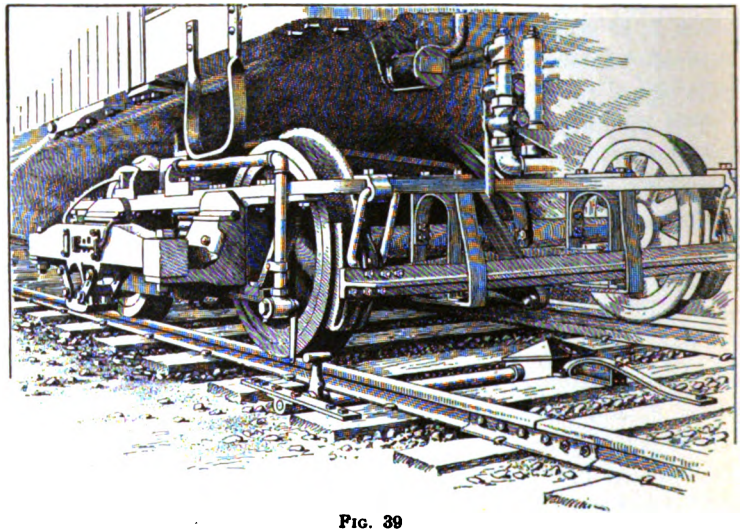

FIG. 39

red light for danger. Each of the signals, however, shows a green light for proceed. Immediately below each of the light signals are provided miniature semaphore arms. These arms take a horizontal position for danger or for caution and a position 60° from the horizontal for proceed.

73. In Fig. 39 is shown an automatic train stop in its raised position. This position is assumed by the stop only when the adjacent signal is at danger. When the signal is at clear, the arm of the stop is down. When in its raised position, this arm will engage the downward projecting

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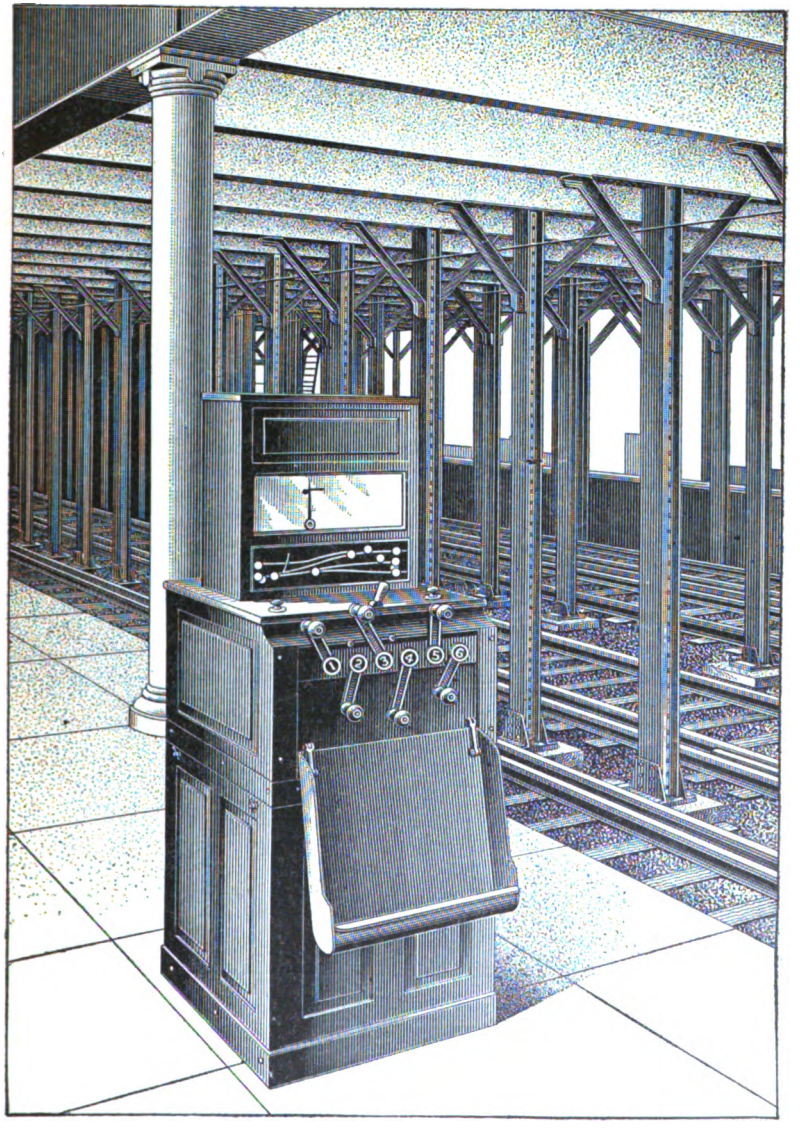

FIG. 40

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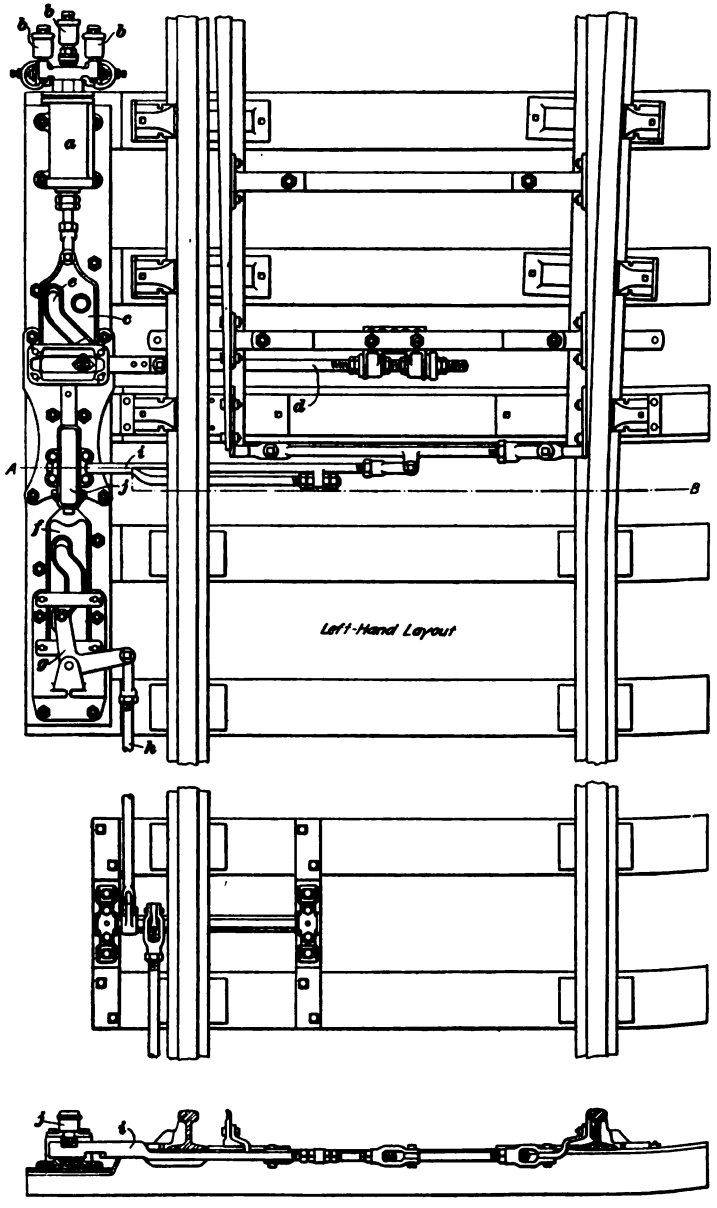

FIG. 41

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handle of an emergency air-brake valve on any train trying to pass and thus set the brakes and stop the train.

74. New York Subway Interlocking System.—On account of the very heavy traffic on the four tracks in the New York Subway, considerable switching is necessary. The switches used are of the interlocking type. According to the American Railroad Association, an **interlocking system** is "an arrangement of switch, lock, and signal appliances so interchanged that their movements must succeed each other in a predetermined order." With proper interlocking, it is impossible to give clear signals for conflicting routes.

While it is beyond the scope of this Section to take up a detailed analysis of the complicated electropneumatic interlocking system, nevertheless, the type of electropneumatic interlocking machine shown in Fig. 40 and the electropneumatic interlocking switch shown in Fig. 41 will be considered.

75. The electropneumatic interlocking machine, Fig. 40, is usually located on a station platform, and is used for operating the crossover switches and route signals. The small levers *1* to *6* control the current supply to the electropneumatic valves, and these valves actuate the air cylinders that move the switches and route signals. The positions of the signals and switches are indicated by the miniature semaphore and by the small lamps in the indicator at the top of the box.

76. The air cylinder of the electropneumatic interlocking switch, Fig. 41, is shown at *a*; the electropneumatic valves at *b*, the cam-plate for moving the switch at *c*, and the switch rod at *d*. At one end of this switch rod is a cam-pin, or roller, that projects into the slot *e* of the cam-plate. The roller and switch rod are moved by the action of the slot *e* in the cam-plate, which is connected directly to the piston of the air cylinder. At *f* is shown another cam-plate, which actuates crank *g*, and at *h* is shown a connecting-rod attached to a detector bar by a rocker-shaft. The detector bar lies

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outside of the rail near the switch and is normally just below the top of the rail; when raised, it is slightly above the rail. When a car is passing over the bar, it can be raised only slightly, since it will come in contact with the treads of the wheels. The lever *g* is thus locked in its position in cam-plate *f*, and the switch cannot be thrown until the entire train is clear of the switch.

Lock rod *i* has two notches in it, while rod *j*, which is moved by the air piston, has two lugs on it. One of these lugs enters one of the notches on the lock rod when the switch is closed, and the other one enters the other notch on the rod when the switch is open. The switch is thus locked in either position, as shown in the sectional view. The first movement unlocks the switch, the next movement sets the detector bar and shifts the switch from one position to the other, and the last movement locks the switch in its new position.

DOUBLE-RAIL RETURN

77. Where conditions permit, it is sometimes desirable to use both rails for the return path of the propulsion current, in order to reduce the drop of potential in that portion of the railway circuit. In a signal system using both rails for the propulsion current as well as for the signaling current, the rails are insulated into block sections by rail insulators, and the rails are then connected together at the ends of the block by means of bonds that have low ohmic resistance but a high reactance. The centers of two adjacent bonds are connected together. Two bonds of this type are shown in Fig. 42.

78. In Fig. 43 is shown the wiring diagram of a signal system using both track rails for the return of the propulsion current. The bonds are shown at *a*, the track transformers at *b*, and the track relays at *c*. The direction of flow of the propulsion current, which is a direct current, is shown by the full-line arrows. The direction of flow of the alternating current for the signals at a time when the left-hand terminal

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of the secondary coil of the track transformer is positive, is shown by the dotted-line arrows.

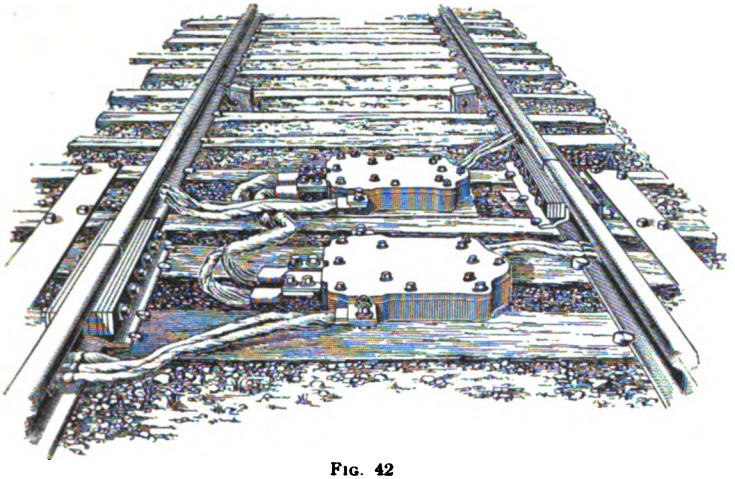

FIG. 42

The direct current in the bonds either flows from both ends to the center or from the center to both ends. Thus,

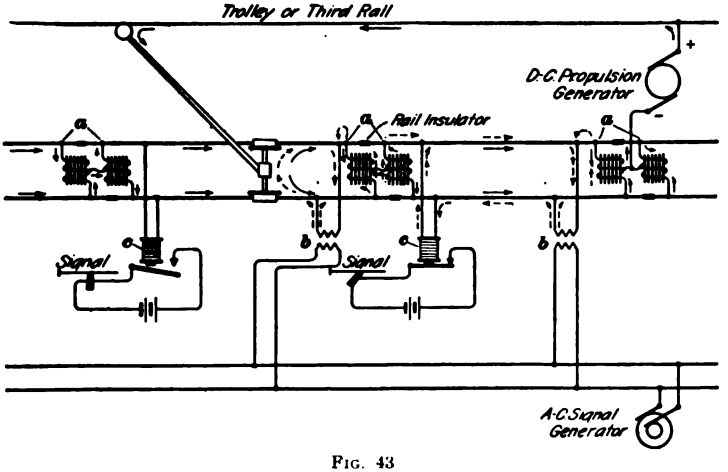

FIG. 43

if the currents flowing in each half bond are equal, their magnetizing effects on the open iron core of the bond will

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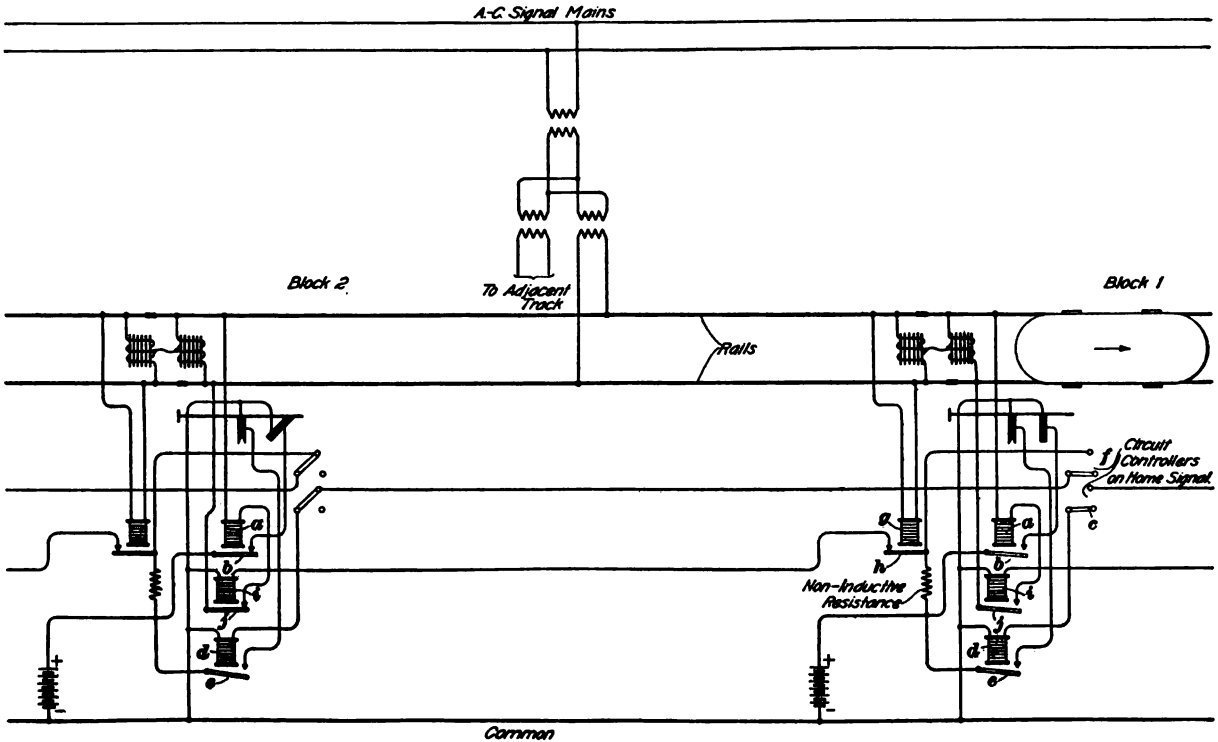

FIG. 44

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neutralize each other. The signaling current, however, flows from end to end of the bonds.

The bonds are so designed that they offer enough impedance to the signaling current to prevent the track relay from being short-circuited. The track relay is also connected in parallel across the two rails.

In this system, the inductive and non-inductive resistances used in the single-track system are omitted, as there is little flow of direct current through either the track transformer or the track relay. The track transformer has a closed iron core.

The signals are set to danger by the action of the truck and wheels of the entering train, which short-circuit the track relay. The track relay controls the battery circuit that operates the signal mechanism.

79. Long Island Railroad Signal Wiring System. In Fig. 44 is shown a wiring diagram of the double-rail-return signal system used on the Long Island Railroad. When a train is in block *1*, alternating-current track relay *a* is short-circuited and switch *b* is opened. This action causes the home signal of block *1* to go to the stop position. Switch *c* is opened by the action of the home signal of block *1*, and the direct-current relay *d* is deenergized. Switch *e* opens and sets the distant signal of block *1* at danger. The distant signal of block *2* is set at caution by the opening of switch *f*, the deenergizing of the direct-current relay *d*, block *2*, and the opening of switch *e*, block *2*. The home signal of block *2* remains at clear.

There are two track relays in this system, one at each end of the block. In case the track relay *a* at the left end of block *2* is short-circuited by a train, the switch *b* at that end will be opened and the home signal moved to stop. If a train happens to back into the right end of block *2*, alternating-current track relay *g* will be short-circuited, switch *h* opened, relay *i* at the left end of block *2* deenergized, switch *j* opened, relay *a* deenergized, switch *b* opened, and the home signal of block *2* moved to stop. The use of two relays also

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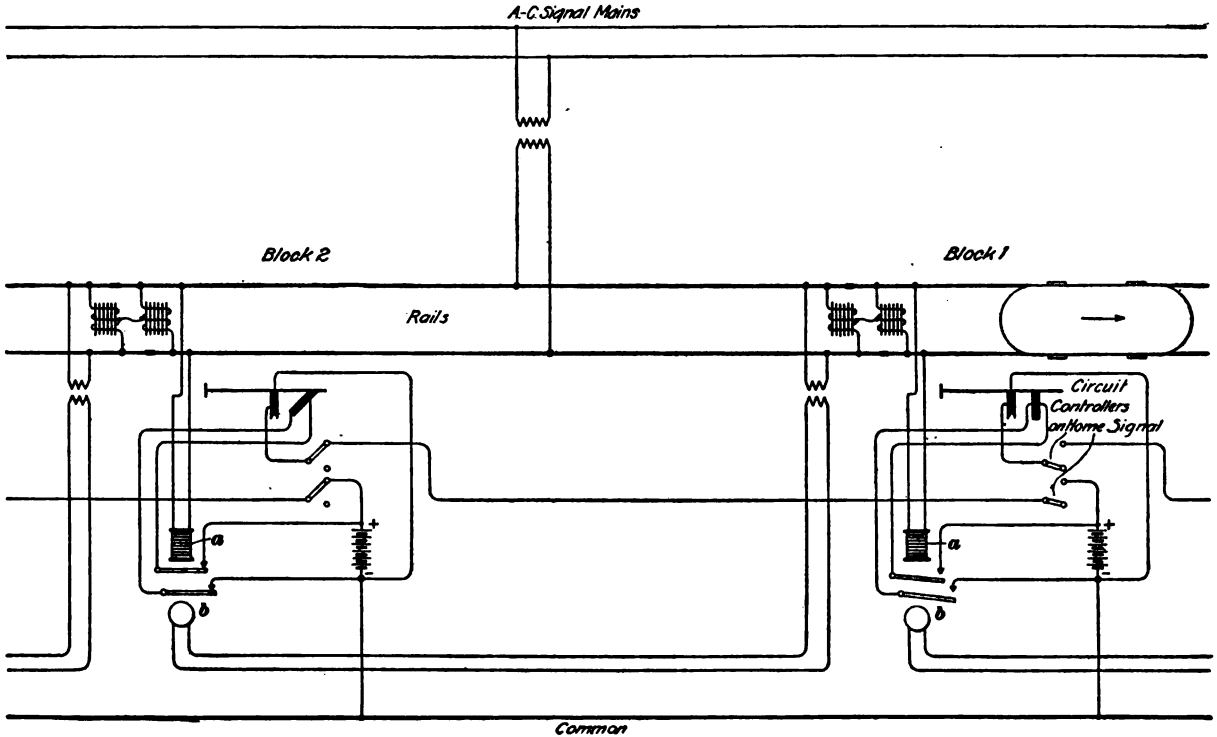

FIG. 45

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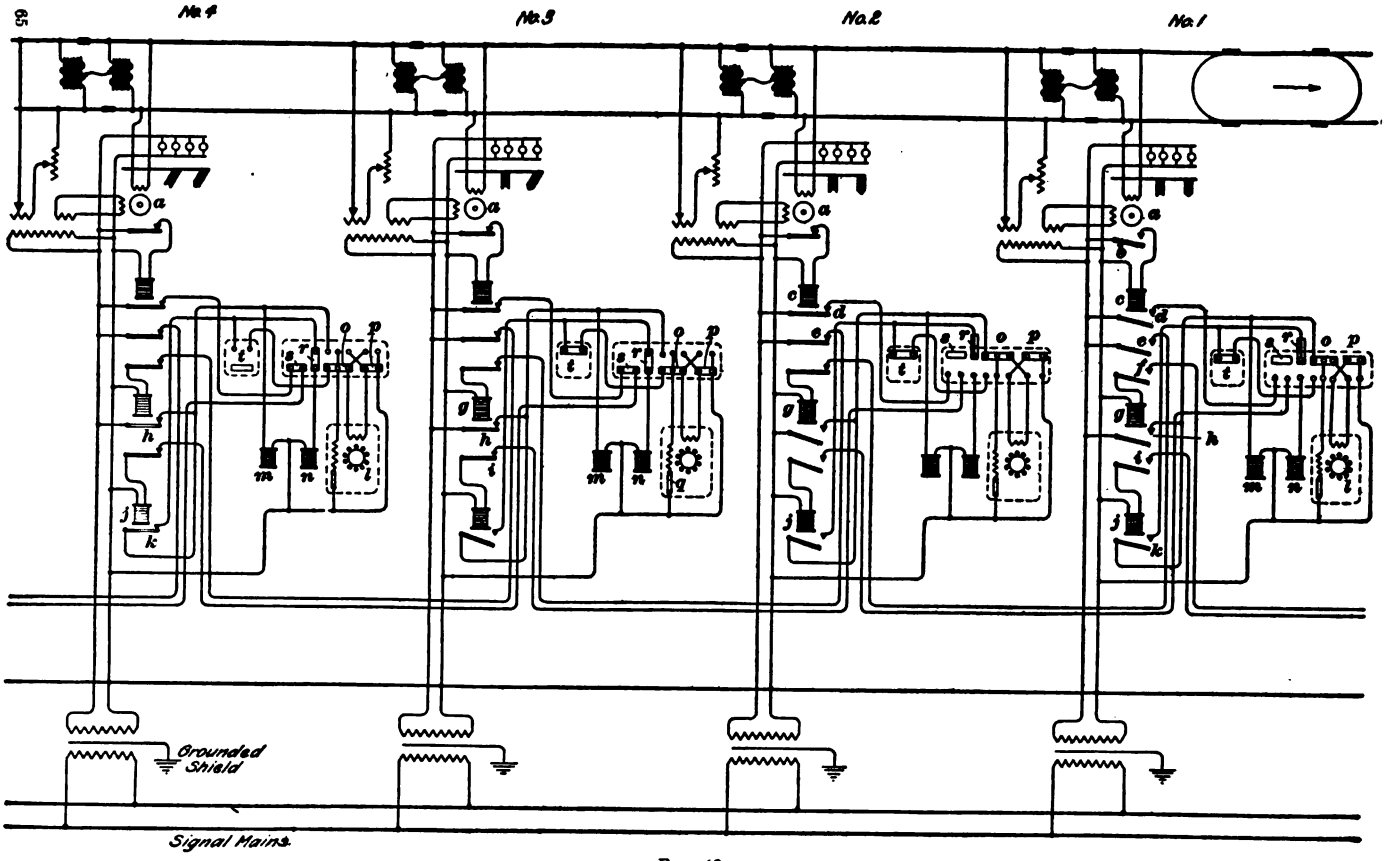

FIG. 46

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tends to keep the signals at danger as the train progresses through the block. If only one relay were used in this system, as at *a*, the relay would have a tendency to become energized after the train passed the middle of the block where the track transformer is connected. Small electric motors are used to lift the semaphore blades to clear.

80. West Jersey and Sea Shore Railroad Signal Wiring Diagram.—In Fig. 45 is shown a wiring diagram of the double-rail return signal system used on the West Jersey and Sea Shore Railroad. In this signal system, the field coil *a* of the motor-type track relay is energized from one end of the block, and the wire wound armature *b* of the relay is energized from the other end. When the block is clear, both the field and the armature are active and the armature is turned to its clear position. When a train is in the block, the current through either the armature or the field, or both, is decreased and the relay armature turns, thus operating contacts that cause the signals to go to danger and caution.

If there is a train in block *1*, as indicated, the two relay contacts of track relay *a* open and thus throw the home signal for block *1* to danger. This action opens the two switches controlled by the home signal. One of these switches opens the circuit of the distant signal of block *1*, thus throwing that signal to danger, and the other switch opens the circuit of the distant signal of block *2*, thus causing that signal to go to caution. The semaphore arms are lifted to clear by means of small electric motors.

81. New York Central and Hudson River Railroad Signal Wiring Diagram.—Both the single- and the double-rail return systems are used in the electric zone of the New York Central and Hudson River Railroad. In Fig. 46 is shown the block-signal connections of the double-rail return system used on this railroad. Reactance bonds with iron cores are employed, and alternating current is used for operating the signal circuits. The track relay *a*, Fig. 46, is of the two-phase induction-motor type. Current for one of the phase windings is

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supplied from the track circuit, and for the other phase winding current is supplied through transformers from the signal mains. The current in the track circuit is out of phase with that in the main signal circuit, owing to the self-induction of the iron rails of the track circuit. The two currents, which differ in phase, set up a revolving-field effect when applied to the windings of the relay, and cause the relay armature to turn through an angle of 37½°. The armature either closes or opens the circuit of a secondary track relay, depending on whether a train is in the block. The secondary track relay operates contact switches that control the motor mechanism operating the signals.

82. In Fig. 46, the train is in the right-hand block. Track relay *a* opens switch *b* and the circuit of the secondary track relay *c*. Relay *c* being thus deenergized, opens switches *d*, *e*, *f*, and the circuit of home relay *g*; relay *g* being deenergized, opens switches *h* and *i*, and the circuit of distant relay *j*; and relay *j* being deenergized, opens switch *k*.

The connections of the ¼-horsepower induction motor *l* that operates the signal mechanism are as shown. The motor runs in one direction when clearing the home signal, and in the opposite direction when clearing the distant signal. The home slot magnet is shown at *m*, and the distant slot magnet at *n*. If, after both signal arms are at danger, the home slot magnet is energized, the motor operates to clear the home signal and to keep it at clear; also, when the distant slot magnet is energized, the motor operates to clear the distant signal and to keep it at clear. The signal arms fall to danger by gravity when the home slot magnet and the distant slot magnet are deenergized.

83. Owing to the presence of the train in block *1*, both slot magnets are deenergized and the signal arms are at danger. Since relays *g* and *j*, block *2*, are deenergized, both slot magnets of block *2* are deenergized and the signal arms are at danger. Track relay *a* and secondary track relay *c*, block *2*, are active, and switches *d* and *e* are closed. Switch *e*, block *2*, closes the circuit of relay *g*, block *3*, and relay *g*,

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closes switches *h* and *i*. The circuit of switch *i*, block *3*, is incomplete at the home-signal circuit controller of block *2*. Switch *h*, block *3*, energizes *m* and allows current to flow to the motor through the contact plates *o* and *p* on the home-signal circuit controller. These plates at the beginning of the operation for clearing the home signal are in the position shown in blocks *1* and *2*.

The motor field coils differ in self-induction, and a revolving magnetic-field effect is set up. As the motor speeds up, an automatic centrifugal switch *q* opens the starting coil, and the motor runs as a single-phase motor. When the motor raises the home-signal arm to clear, the home-signal circuit controller is thrown over so that the contact plates *o*, *p*, *r*, and *s* are in the lower position, as shown in blocks *3* and *4*. The connections of one field coil have been reversed, so that the motor, when it starts to clear the distant signal, may revolve in the opposite direction to its former direction of movement. At block *3*, the home signal is at clear and the distant signal at danger.

The circuit through relay *j*, block *4*, is now complete, and switch *k*, block *4*, is closed. Distant slot magnet *n* is energized. At the beginning of the operation for clearing the distant signal, the contact plate *t* on the distant-signal circuit controller is in the upper position. Current can flow from switches *h* and *k*, through plate *t*, to the motor. The motor now drives the distant signal to clear. In raising, the rod that drives the distant signal to clear causes contact plate *t* to move to the lower position, thus opening the motor circuit. In block *4*, both signals are at clear, and if a train should enter this block, slot magnets *m* and *n* would become deenergized and both signals would fall to danger.

84. Hudson and Manhattan Railroad Signal Wiring Diagram.—In the Hudson River Tunnel of the Hudson and Manhattan Railroad Company both rails conduct the direct-current used for propulsion purposes and the 25-cycle alternating current used for the signal system. Reactance bonds with iron cores are used in the rail-return circuit. To

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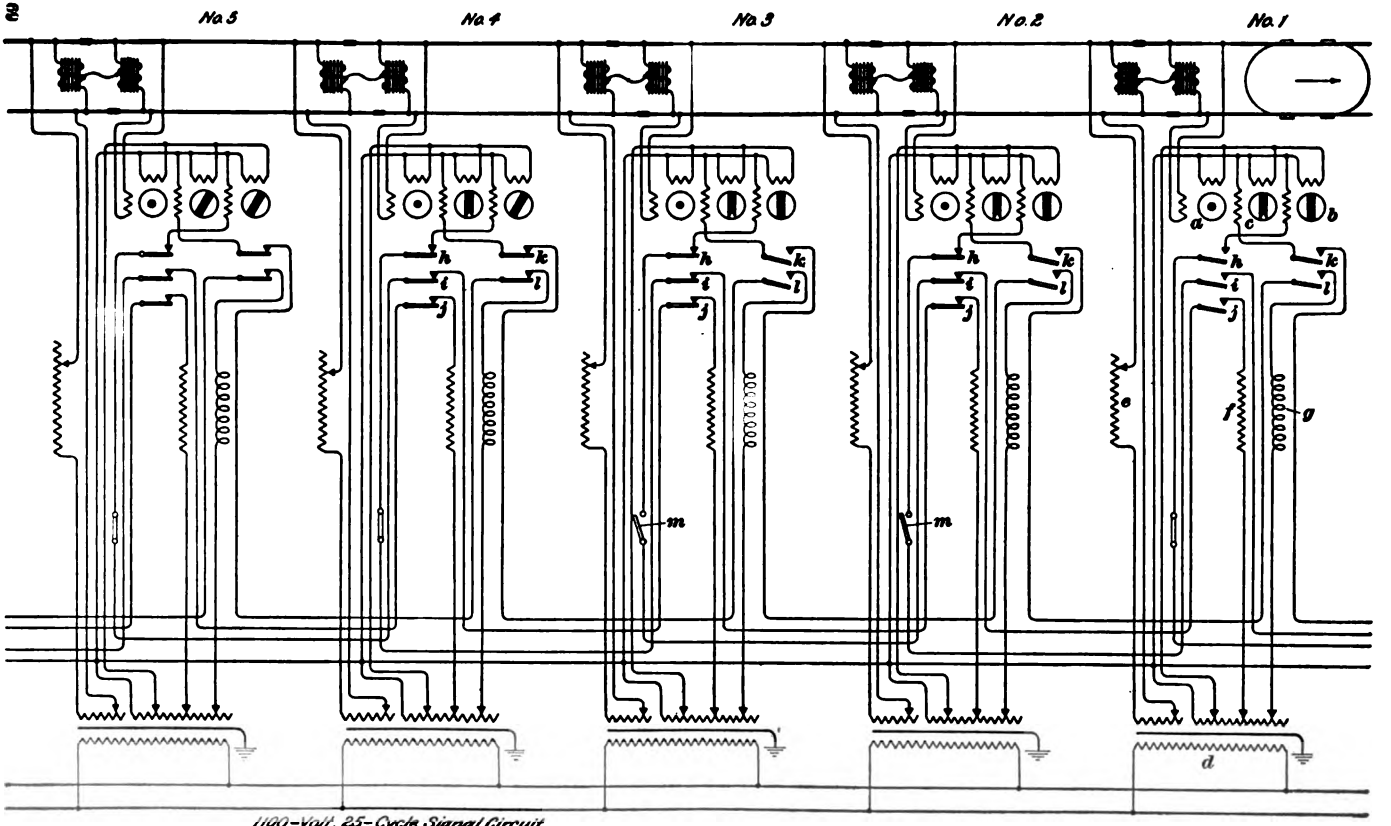

FIG. 47

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provide for maximum safety and yet have maximum train capacity in the tunnel, a two-block overlap is used. One complete block, protected by three home signals set at danger, is three overlaps in length. The signals are so arranged that a train in any block is protected by three red stop signals and four yellow caution signals, as well as by automatic train stops in the two blocks immediately behind the train.

85. In Fig. 47 is shown the connections of the block signals employed in this tunnel. The track relay *a* is of the two-phase induction-motor type and operates three contact switches. The home signal *b* and the distant signal *c* are operated by two-phase induction motors. The home signal controls two contact switches. The primary coil of transformer *d* is connected to the signal-circuit mains, and the secondary coils are connected to the track and to the local signal circuits. The secondary coils are protected from any accidental high voltage, such as might be impressed on them in case of insulation failure, by a grounded shield, as indicated just above the primary coils in Fig. 47. A resistance grid is shown at *e*, a resistance coil at *f*, and a reactance coil at *g*. The currents in the two sets of field coils of each induction motor differ in phase, and the motor operates to keep the signals at clear when the local signal circuits are closed.

86. A train is in the block at the right. The track relay of that block opens its three contact switches *h*, *i*, and *j*, and switch *h* opens the circuit of one of the sets of field coils of the home-signal motor. Signal *b* goes to danger and, in turn, opens the two contact switches *k* and *l*. The open circuit at switch *k* causes the distant signal of block *1* to go to caution. Switch *i* opens the circuit through one of the sets of field coils of the home-signal motor of block *2*. The home signal of this block goes to danger, and its switches *k* and *l* open. Switch *l*, block *1*, and switch *k*, block *2*, open one of the field circuits of the distant-signal motor in block *2*, and that distant signal goes to caution. The home signal of

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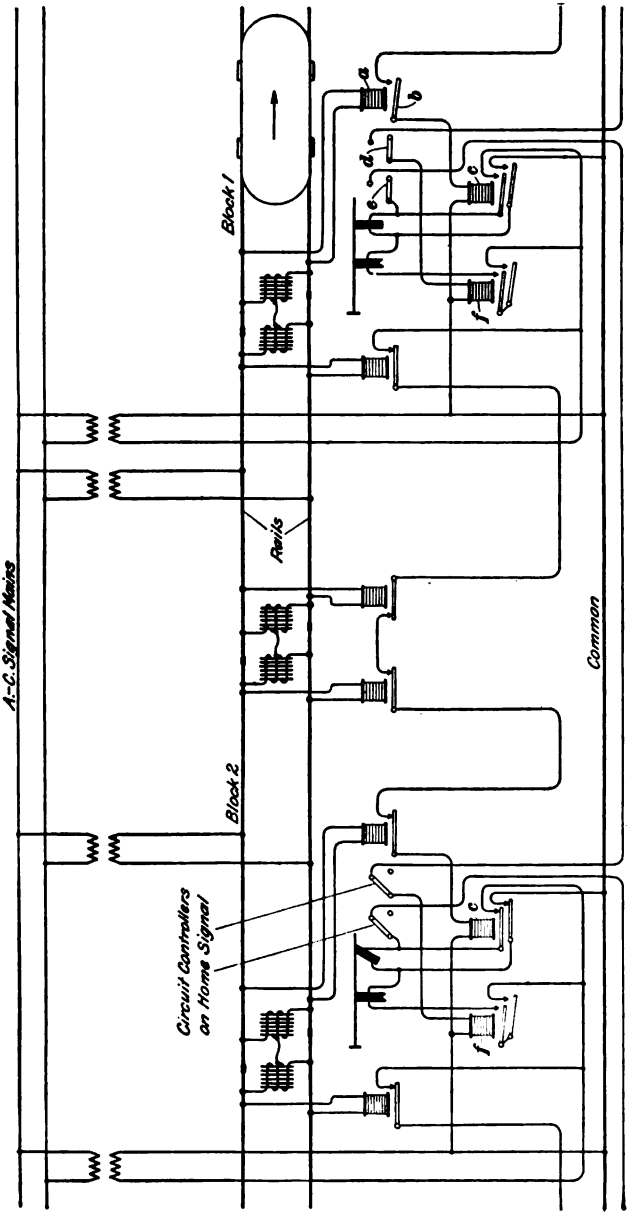

FIG. 48

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block *3* is moved to danger because of the open circuit at switch *j*, block *1*. The distant signal of block *3* is moved to caution on account of the open circuit at switch *k*, block *3*. The distant signal of block *4* goes to caution because of the open circuit at switch *l*, block *3*.

Three home signals are set at danger and four distant signals at caution; also, the automatic train stops in blocks *2* and *3* are active. The connections for the automatic train stops are not shown in the sketch. A switch *m* is operated by the automatic train stop.

The signals are of the illuminated-disk type, having no arms and giving indications by red and green lights. The vanes that either expose or hide the lights are moved by the induction motors.

87. New York, New Haven, and Hartford Railroad Signal Wiring Diagram.—In Fig. 48 is shown a wiring diagram of the signal system used in the electrical zone of the New York, New Haven, and Hartford Railroad. The propulsion current on this road is an alternating current having a frequency of 25 cycles. The signal installation is similar to those used for the double-rail return system employing direct current for propulsion. However, the iron cores of the inductive bonds have no air gap, and the track frequency relays are so designed that they will operate with the 60-cycle alternating signaling current but not with the 25-cycle alternating propulsion current.

The relay has a double vane and a double magnetic circuit, but it has only one set of magnetizing coils. The two magnetic circuits are designed so that alternating current of a frequency of 25 cycles tends to keep the relay contacts open; but this action is normally overcome by the 60-cycle signaling current, which keeps the relay contacts closed as long as no train is in the block. The local signal circuits and the control circuits for the next signals in the rear are supplied with current from the alternating-current signal mains.

88. With a train in block *1*, Fig. 48, track relay *a* is deenergized and its contact switch *b* opens, thus deenergizing

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relay *c*. The opening of the switches under *c* causes the home signal of block *1* to go to danger and the circuit switches *d* and *e* controlled by the home signal to open. Switch *d* opens the circuit of relay *f*, and the two switches below *f* then open. The local circuit containing the two switches under relay *f* was opened when the lower switch under relay *c* opened; therefore, the home and distant signals in block *1* go to danger and to caution at practically the same time. The open switch *e* and the open upper switch under *c* which, when closed, are connected in the circuit of the right-hand track transformer, cause relay *f*, block *2*, to become deenergized; and this action, in turn, interrupts the circuit controlling the distant signal, block *2*, and sets that distant signal at caution. Relay *c*, block *2*, is still energized, so that the home signal of block *2* remains at clear. The semaphore arms are actuated by a motor and by gravity. The operation of the motor is controlled by the signaling circuits.

SIGNAL RULES

89. It is practically impossible to formulate a set of signal rules covering all signal systems. The following are extracts from the book of rules issued to motormen and enginemen of the New York Central and Hudson River Railroad Company for the running of steam and electric trains over the electrical zone of this railroad system. In general, these rules are similar to those issued by roads having like traffic conditions.

PRINCIPLES OF LOCATION

Wherever practicable, signals will be located as explained below, but where conditions require other construction, special locations will be made and described by proper notice.

Signals, if practicable, will be located either over or upon the right of and adjoining the track upon which trains are governed by them.

Wherever the space between tracks is not sufficient for signal posts to be located next the track to which they refer, the posts carrying the arms will be located either on a signal bridge, bracket post, or a post to the left of the track.

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The number of poles on a bracket post correspond with the number of tracks, counting from the location of the post itself, which are governed bythe signals on the bracket post.

Where there is an unsignaled track between the bracket post and the track which it is to govern, an unsignaled pole is used on the bracket post to signify the unsignaled track.

Reverse movements from the established direction and movements on or from sidings may be governed by dwarf signals placed, wherever possible, to the right of the movements governed.

Diverging movements from any running track in the established direction are governed by home signals located one above the other on the same post. The upper home signal will govern the main, or superior, route, and the lower home signal the inferior, diverging routes. The middle home signal, if any, will govern any important branch or connection. (See Figs. 49, 50, and 51.)

Where the home-signal post at any interlocking plant also carries the distant signal for the next home signal in advance, the distant signal will be placed next below the home signal governing the route. (See Figs. 52, 53, and 54.)

GENERAL RULES

1. Interlocking signals, unless otherwise provided, do not affect the movement of trains under the time table or train rules; nor dispense with the use or observance of other signals whenever or wherever they may be required.

2. *Normal Indication of Signals.*—The normal indication of interlocking signals is stop, except the distant, which is caution, be prepared to stop at the home signal.

3. *Type of Signals.*—The signals used are of the 60° semaphore pattern, the arms that govern being displayed to the right of the signal post as seen from an approaching train.

4. Indications are given by two positions of the arms, and in addition by lights of prescribed color, by night.

5. The arms of home and dwarf signals have a square end, and are painted red with a white band near the end.

6. *Home Signals.*—The arm of the home signal in the horizontal position by day, and in addition by the display of a red light by night, indicates stop. (See Fig. 55.)

7. When in the stop position, the home and dwarf signals must not be passed until authority to do so is given by train order, or by proceed card.

8. The arm of the home signal, at an angle of 60° below the horizontal by day, and in addition by the display of a green light by night, indicates proceed. (See Fig. 56.)

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9. *Distant Signal.*—The arm of the distant signal has a forked end and is painted yellow with a black <-shaped band near the end. (See Fig. 57.)

10. The arm of the distant signal in the horizontal position by day, and in addition by the display of a yellow light by night, indicates caution, be prepared to stop at the home signal. (See Fig. 57.)

11. The arm of the distant signal, at an angle of 60° below the horizontal by day, and in addition by the display of a green light by night, indicates proceed. (See Fig. 58.)

12. The arm of the dwarf signal at an angle of 60° below the horizontal by day, and in addition by the display of a green light by night, indicates proceed. (See Fig. 59.) (A horizontal position of the arm indicates danger. A red danger-signal light is displayed at night south of 57th Street, and a purple danger-signal light is displayed at night north of 57th Street.)

13. *Pot Signal.*—When the pot signal is used as a switch indicator, green will signify, switch set for main route; yellow will signify, switch set for inferior route; purple will signify, an open derail. (See Figs. 60, 61, and 62.)

When used as a dwarf signal, it will display the same color indications as dwarf signals. (See Fig. 63.)

14. A signal improperly displayed, a white light by night, displayed on any signal, or the absence of a signal at a place where a signal is usually shown, must be regarded as a stop signal and the fact reported to the superintendent.

15. Motor and engine crews should, wherever possible, observe the position of all semaphore arms at night to see that they correspond with the indications given by the lights.

16. Motormen and enginemen must know the indications of all fixed signals before passing them. At railroad crossings, drawbridges, junctions, or train-order offices, they will require the fireman or helper to observe and communicate the indications of all signals. On all electrically operated trains, the operating inspector or motorman's helper will call the position of all signals to the motorman. When interlocking signals are obscured, the motorman or engineman will bring his train under immediate control and run cautiously until he can positively distinguish the signals, and he must not exceed a speed which would make it impossible for him to stop his train at a point from which the home signal can be plainly seen.

17. When backing, or when cars are pushed ahead of an engine, the conductor of the train will observe all signals and repeat their indications by hand signals.

18. Trains or engines must be run to, but not beyond, a signal indicating stop.

19. If a clear signal is changed to a stop signal before it is reached, stop must be made at once. Such occurrences must be reported to the superintendent and signal engineer.

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20. Where fixed signals are in use, trainmen must not give proceed hand signals as against the indications of the fixed signals, except as provided in rule 23.

21. Whenever the home signal of an interlocking station cannot be cleared, trains will be forwarded on proceed card. Where there is more than one home signal controlled from an interlocking station, a proceed card must be had for each home signal to be passed at stop by the train.

22. Home signals protecting drawbridges while at stop, must not be passed by an engine or train until a proceed card, Form P. C. 1, is received by the motorman or engineman from the drawbridge foreman, indicating that the signal is out of order and that the derails, bridge rails, and locks are in proper position for the safe movement of the train. Motorman or engineman receiving a proceed card, Form P. C. 1, to pass a home drawbridge signal at stop, will proceed with the train under full control and will observe that derails and bridge rails are in proper position before passing over them. Drawbridges are protected by derails in both directions in all tracks.

23. Motor, engine, and train crews will not accept proceed hand signals as against the fixed signal of an interlocking plant until they have brought their train or engine to a stop, and have obtained from the signalman full information regarding the situation. After having made sure that they are fully protected, they may accept hand signals authorized by the signalman for switching movements, when same are given from the ground, on the track on which the movement is to be made, and in such a way that there can be no misunderstanding as to the train or engine for which the hand signals are intended.

24. The motorman or engineman of a train which has parted must sound the whistle for train parted on approaching an interlocking station.

25. The motorman or engineman receiving a train-parted signal from a signalman must answer by the whistle signal for train parted.

26. Grates must not be shaken, ash pans cleaned, nor sand used over any part of any interlocking plant.

27. When stopping to take coal or water, the train must be stopped outside of all derails before the engine is cut off.

28. Flying switches must never be made through an interlocking plant.

29. Trains or engines stopped in making a movement through an interlocking plant must not move in either direction until they receive the proper signals from the signalman.

30. Conductors of all trains and motormen or enginemen of light engines must report to the superintendent any unusual detention at interlocking plants.

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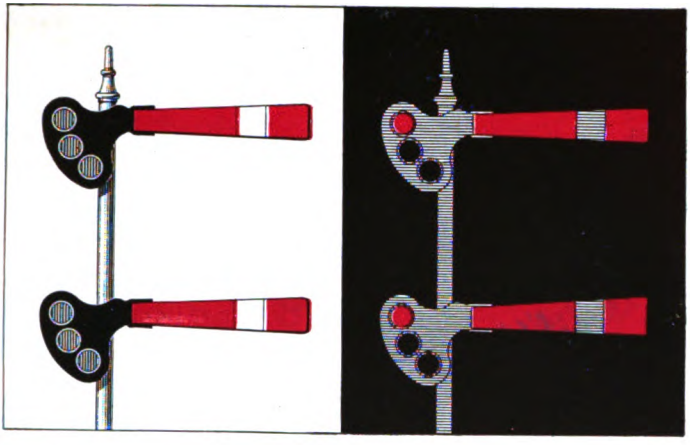

FIG. 49

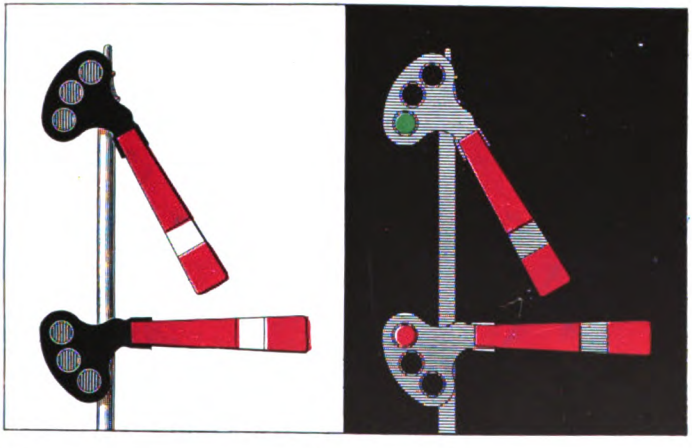

FIG. 50

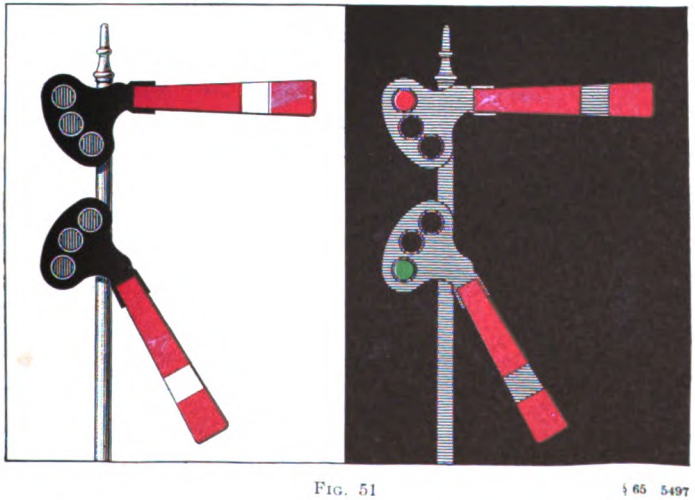

FIG. 51

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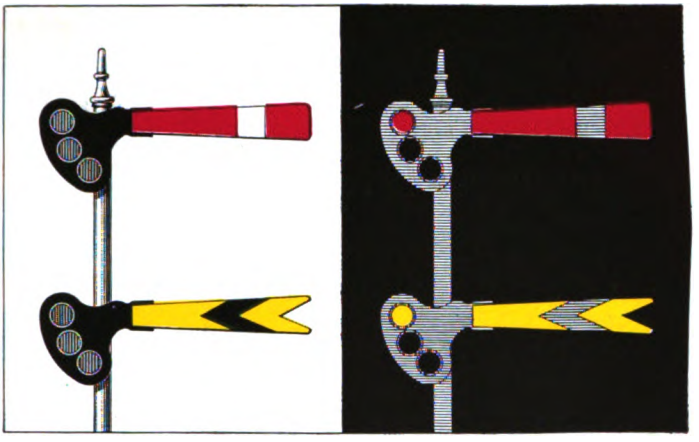

FIG. 52

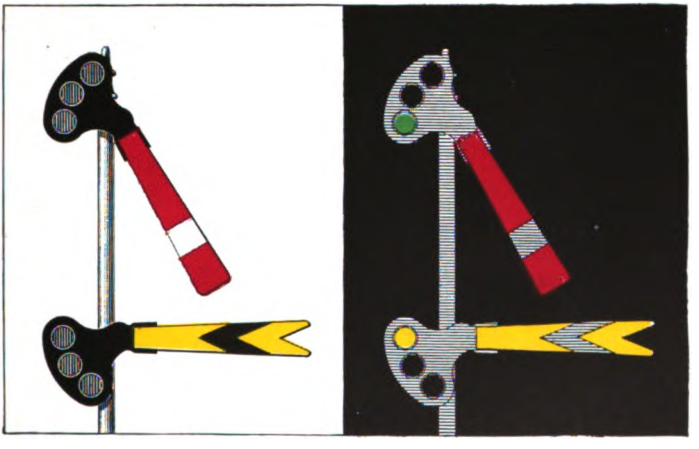

FIG. 53

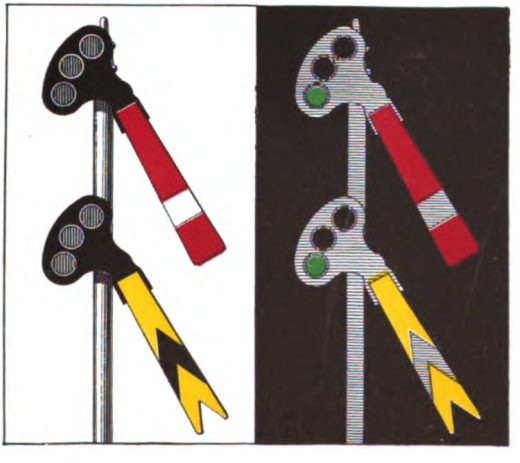

FIG. 54

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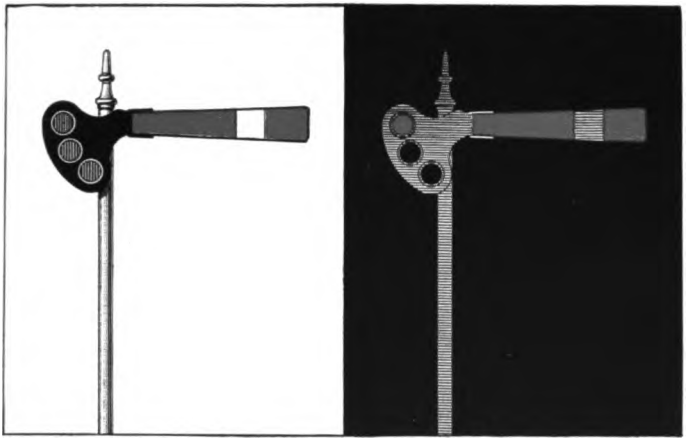

FIG. 55

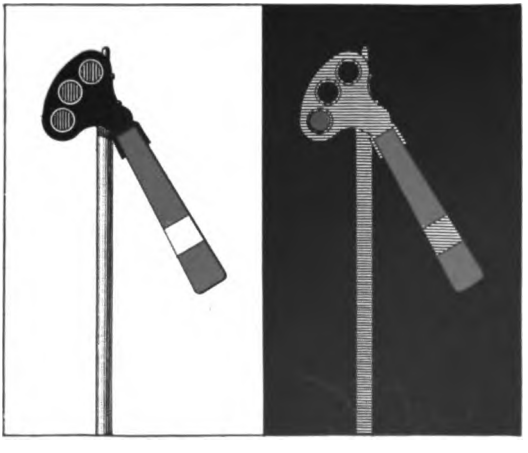

FIG. 56

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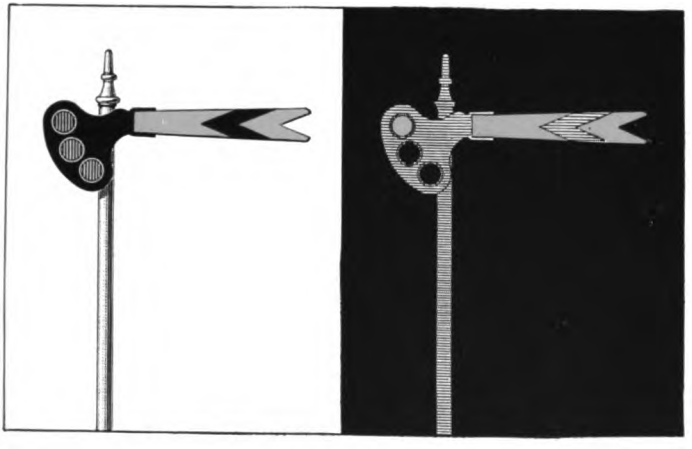

FIG. 57

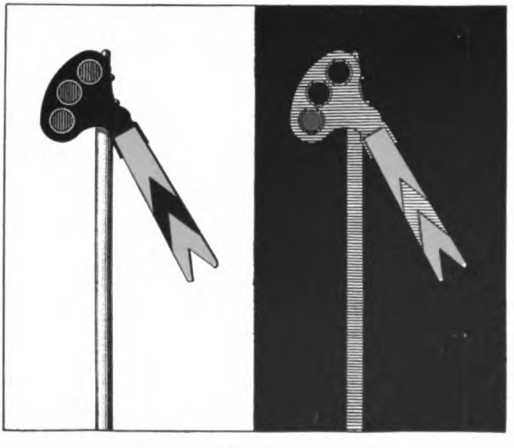

FIG. 58

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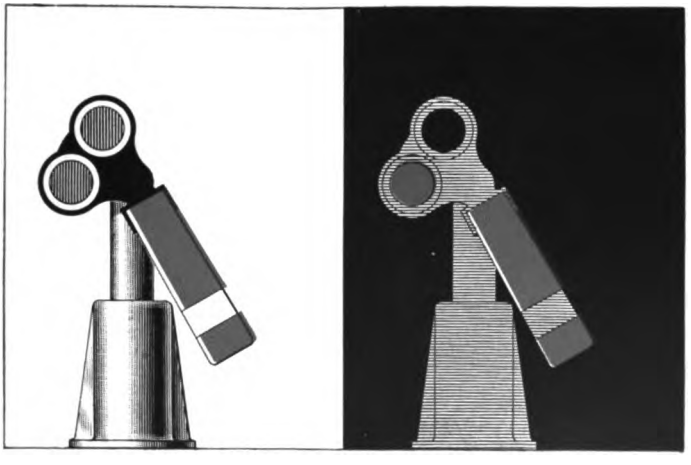

FIG. 59

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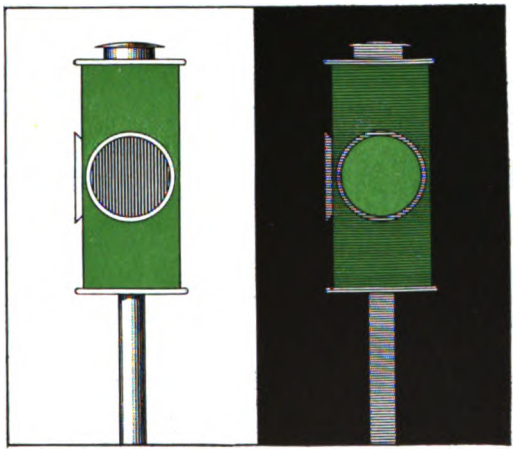

FIG. 60

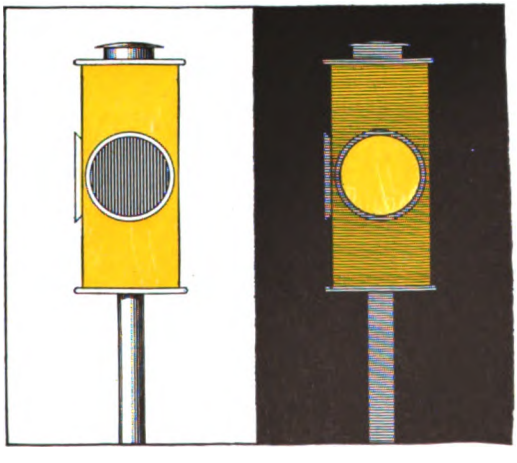

FIG. 61

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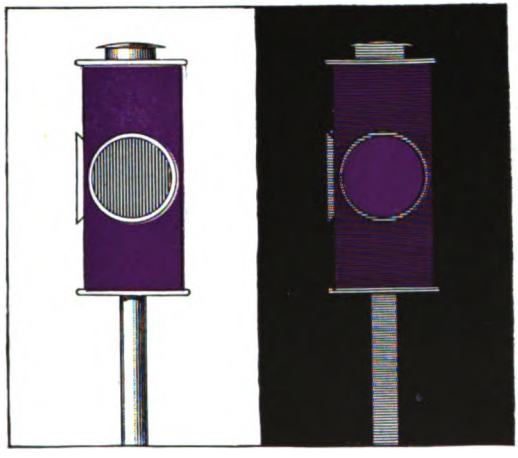

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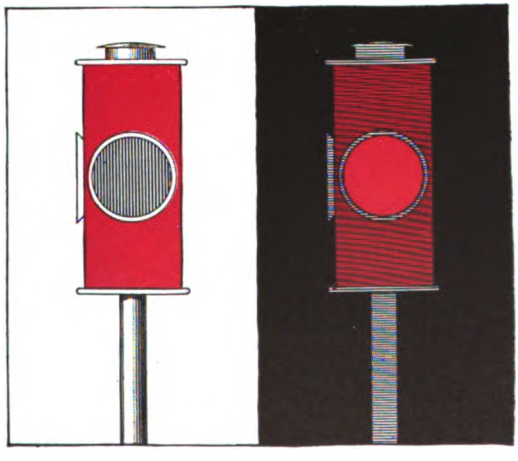

FIG. 63

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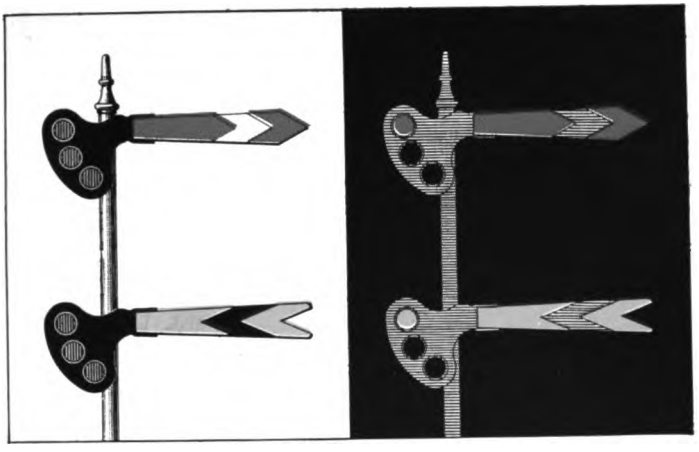

FIG. 64

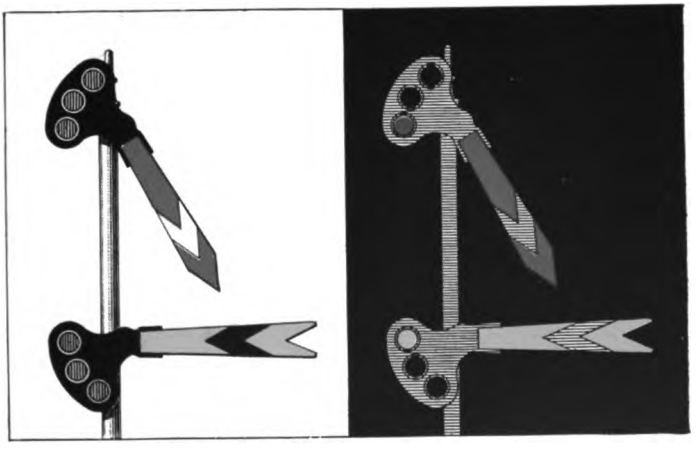

FIG. 65

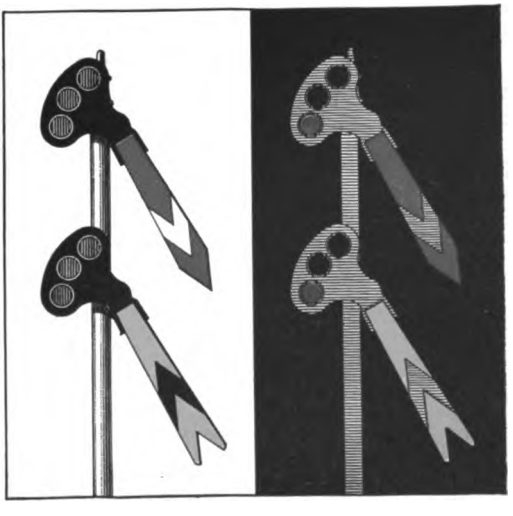

FIG. 66

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N. R. 3907. Form P. C. 1

N. Y. C. & H. R. R. CO. No._____

ELECTRIC DIVISION

PROCEED CARD

Time_____ **Date**_____

Interlocking Station_____

Block Station No._____

To Motorman or Engineman of Engine _____

Train No._____ **on Track No.**_____

Block Signal cannot be cleared;

Interlocking Signal No._____ **cannot be cleared;**

Proceed with caution.

_____

Signalman

This card must not be issued except in case of failure of block or interlocking home signals and when section ahead has been duly reported clear by the signalman at advance block station or home interlocking signal has failed. The motorman or engineman receiving it properly dated, timed, and signed, will run to next home signal with train under full control, and on completion of trip will send the card to this office.

Where there is more than one home signal controlled from an interlocking plant, a proceed card must be had for each home signal to be passed at stop by the train.

Motormen and enginemen entering a block on proceed card will be held responsible in case of accident.

_____

Superintendent

The principles governing the location of interlocking signals in so far as they apply, govern the location of block signals.

Block signals control the use of the block, but unless otherwise provided, do not affect the movements of trains under the time table or train rules; nor dispense with the use or the observance of other signals whenever and wherever they may be required.

CONTROLLED MANUAL BLOCK SIGNALS

31. Block signals apply only to trains running in the established direction.

32. A signal improperly displayed, a white light by night displayed on any signal, or the absence of a signal at a place where a signal is usually shown, must be regarded as a stop signal and the fact reported to the superintendent.

33. Motormen and enginemen must know the indication of all fixed signals before passing them. On all electrically operated

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trains the operating inspector or motorman's helper will call the position of all block signals to the motorman. When home or distant signals are obscured the motorman or engineman will bring his train under immediate control and run cautiously until he can positively distinguish the signals, and must not exceed a speed at which train can be stopped at a point from which home signal can be plainly seen.

34. A train may be admitted into a block occupied by a preceding train under a train order, Form 19, reading, "Close in on train....." Additional instructions may be included in the order, such as "Assist preceding train, etc." Trains receiving such orders will pass block signal at stop at the block station where order is received and proceed with train under full control. The order will be fulfilled upon arrival at the next block station in advance.

35. Rules 15, 16, 17, 18, 19, and 20 will govern the observance of block signals.

36. Motormen or enginemen of passenger trains will forward to the office of the superintendent, at the completion of each trip, all proceed cards received.

37. Unless directed by special instructions, when two or more trains have been coupled and so run past any block station, they must be uncoupled only at a block station and the signalman notified.

38. When a train takes a siding at a block station, the conductor must immediately notify the signalman when the train is clear of main track and the switch closed.

39. When a train takes a siding it must not again enter the block without the permission of the signalman.

40. The motorman or engineman of a train which has parted must sound the whistle signal for train parted on approaching a block station.

41. The motorman or engineman receiving a train-parted signal from a signalman must answer by the whistle signal for train parted.

42. If the track is obstructed between block stations, notice must be given to the nearest block signalman.

43. If a train is held by a block signal, the conductor must at once ascertain the cause.

44. Conductors must report to the superintendent any unusual detention at block signals.

45. A block station must not be considered as closed, except as provided in the time table or by special instructions.

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AUTOMATIC BLOCK SIGNALS

46. All automatic home block signals are designated by numbers indicating the distance, miles and tenths, from New York, and the number of track which they govern.

47. Automatic block signals apply only to trains running in the established direction.

48. Automatic block signals are of the semaphore type, and unless otherwise designated are permissive signals.

49. Indications are given by not more than two positions of the arm, and in addition, by lights of prescribed color.

50. On automatic block signals, the arms that govern are displayed to the right of the post as seen from an approaching train.

51. The arm of the home automatic block signal has a pointed end and is painted red with a >-shaped, white band near the end. (See Fig. 64.)

52. On automatic block signals, the arm of the home signal in the horizontal position by day, and in addition the display of a red light by night, indicates stop. (See Fig. 64.)

53. The arm of the home automatic block signal at an angle of 60° below the horizontal by day, and in addition the display of a green light by night, indicates proceed. (See Fig. 65.)

54. The arm of the distant automatic block signal in the horizontal position by day, and in addition the display of a yellow light by night, indicates caution, be prepared to stop at the home signal. (See Fig. 65.)

55. The arm of the distant automatic block signal at an angle of 60° below the horizontal by day, and in addition by the display of a green light by night, indicates proceed. (See Fig. 66.)

56. A signal improperly displayed, a white light by night displayed on a signal, or the absence of a signal at a place where a signal is usually shown, must be regarded as a stop signal and the fact reported to the superintendent.

57. When a home automatic block signal indicates stop, trains or engines must stop at or before reaching the signal and, after having stopped, may proceed with caution to the next signal, expecting to find a train, an open switch, a broken rail, or some other obstruction in the block.

58. Motormen or enginemen entering a block as provided in rules 56 and 57, will be held responsible in case of accident.

59. On all electrically operated trains, the operating inspector or motorman's helper will call the position of all signals to the motorman. When the home or distant signals are obscured, the motorman or engineman will bring his train under immediate control and run cautiously until he can positively distinguish the signals, and must

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not exceed a speed at which train can be stopped at a point from which home signal can be plainly seen.

60. Motor and engine crews, whenever possible, should observe the position of all semaphore arms by night to see that they correspond with the indication given by the lights.

61. When a train is stopped by a signal which is evidently out of order and not so indicated, the fact must be reported to the superintendent and the signal engineer by wire on form S. C. 1.

62. Motormen or enginemen before reporting cause of stop unknown must, if possible, ascertain if such stop was caused by a train in the block, an open switch, a broken rail, or some other obstruction.

63. Switches in or leading to the main track are provided with switch instruments so connected to the switch points that opening the switch in any block will cause the home signal governing that block to indicate stop, and the distant signal to indicate caution, until the switch is again closed.

64. Where switch instruments are provided on main-track crossover switches, the opening of a switch at either end of the crossover will hold the home signal in both directions at stop and the distant signals therefore at caution.

65. Where switch instruments are provided on both switches of a crossover from a siding to a main track, opening either switch of the crossover will hold the home signal on the main track at stop and the distant signal at caution.

66. Trains must be stopped and cars placed on siding clear of the fouling point and insulated track joints, as otherwise the signal for the block in which the switch is located will indicate stop.

67. Trackmen and other employes will report promptly to the superintendent and signal engineer, by wire, all defects noticed in the block-signal system.

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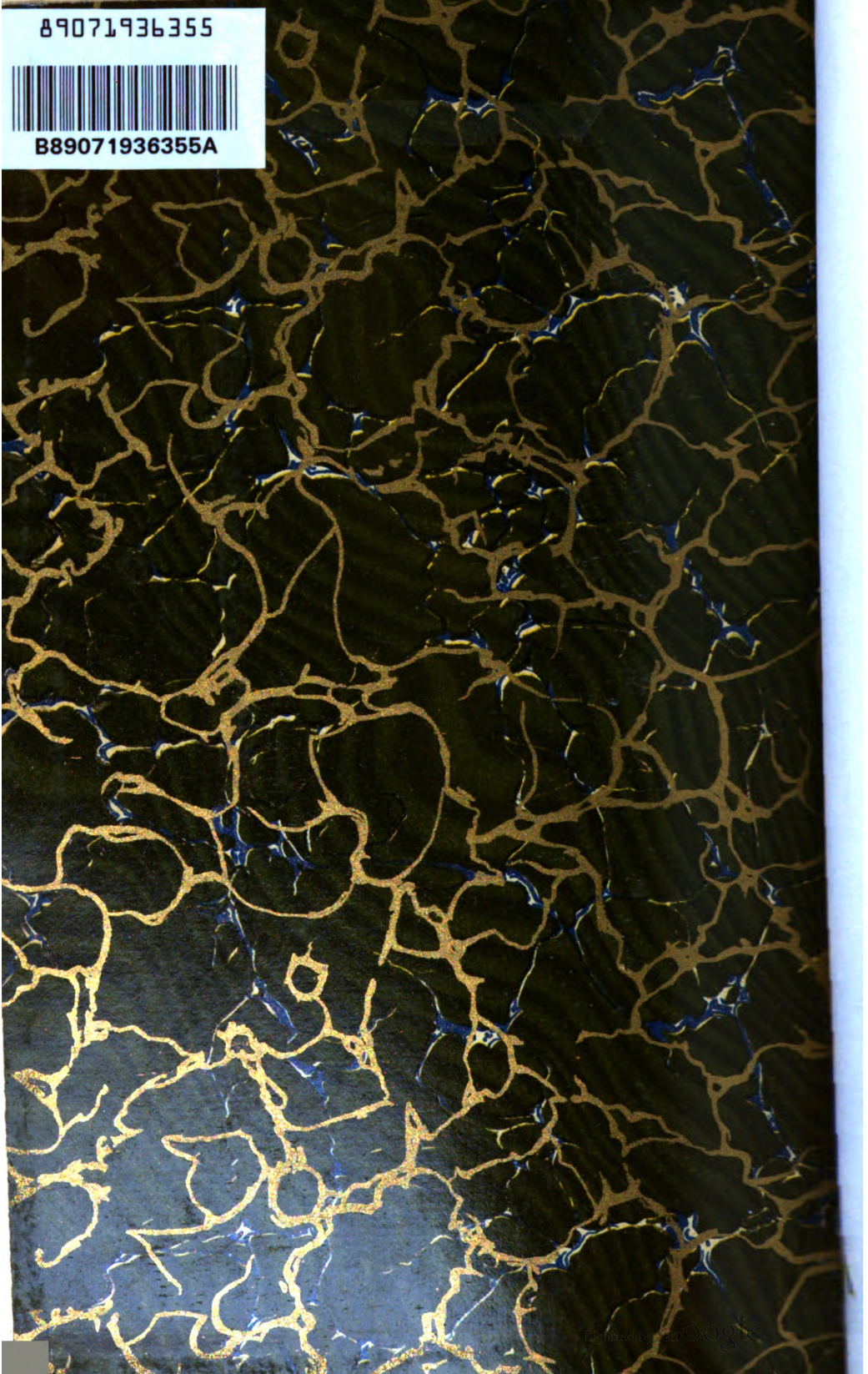

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